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Contents

Plenary speakers

From science to policy: Using science to inform coral reef conservation and management

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Coral reef ecosystems are increasingly vulnerable to climate change and ocean acidification. Other stressors, such as overfishing, nutrient and chemical pollution, habitat alteration and invasive species interact with and exacerbate the effects of climate change. There is hope, however. Recent studies show that when local pressures such as those from overfishing and poor water quality are controlled, coral communities can better recover from acute events, such as thermal bleaching. As our understanding about these valuable ecosystems grows, our challenge is to translate the most recent coral reef science into innovative management strategies that improve reef resilience while meeting the needs of communities that depend upon them. These management scenarios depend on strong, collaborative partnerships that balance multiple types of uses of ocean resources. I will provide an overview of progress made by the U.S. government in managing and conserving the nation's coral reefs, work that is framed by our first-ever National Ocean Policy. While reducing carbon emissions is clearly an important step in restoring healthy oceans and reefs, reducing pressures from other stressors can improve reef resilience. Such adaptation strategies include policies and measures to reduce nutrient runoff, end overfishing through science-based management aimed at sustainability, combat illegal, unreported, and unregulated (IUU) fishing, and protect biodiversity to maintain ecosystem functioning. Innovative community-based solutions are emerging. Adaptation strategies aimed at these multiple and more tractable challenges offer a valuable path forward for coral reef ecosystems and the communities and economies that depend on them.

Monday 9 July, 0900, Plenary Hall 2

Scientific and management challenges in conserving the reefs in the Coral Triangle region: Lessons learnt from Indonesia

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The Coral Triangle Initiative for coral reef, fisheries, and food security (CTI-CFF) in Manado-Indonesia, launched by the leaders of six coral triangle countries on May 2009, represents an historic high-level committment to managing and conserving the reefs in the region. The Coral Triangle region is one of the world's most precious natural wonders, with a magnificent range of marine habitats, including the world's most diverse coral reefs.. At the same time, however, rapid global economic development, increasing demands on coral reef resources, and new technologies, have damaged many coral reefs in the region, and many reefs are severely over-utilized and subjected to destructive fishing practices. These and other emerging pressures such as coral bleaching, crown-of-thorns starfish, coral mining, sedimentation, and pollution, have degraded coral reefs and coastal ecosystems throughout the region in recent decades. In response to these increasing global pressures, CTI-CFF aims to address five very challenging goals that implement improved seascape management, an ecosystem approach to management of fisheries, a regional system of marine protected area, enabling climate change adaptation, and improving status of threatened species. This plenary paper will further elxplore the scientific and management challenges of achieving the CTI goals, especially for securing the future of coral reefs in Indonesia.

Monday 9 July, 1400, Plenary Hall 2

Coral calcification: From cell physiology to ocean acidification

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Biomineralization is a major physiological process leading to the formation of minerals by living organisms(hence called biominerals). Among biomineralization processes, coral calcification is responsible for the largest bioconstructionof the world, the coral reefs. In addition to a huge ecological role, coral skeletons are used for several purposes ranging from taxonomy, environmental archives or as bioimplants for bone surgery. Recent studies suggest that this major process may be altered by a recently-identified threat, ocean acidification, due to dissolution of CO_2 into the sea. Optimal use of coral skeletons and understanding the different sensitivity of coral calcification to ocean acidification require perfect knowledge of the mechanisms controlling the formation of coral skeletons, however, if large progresses have been made these last 10 years, a lot of questions are still pending: What is the chemical composition of the extracellular calcifying medium? How ions are supplied to the skeleton? What is the role of intraskeletal organic matrix? How genes regulate the form of the coral skeleton? Why coral are sensitive to a subtle long-term change in ocean pH although they are daily submitted to much larger pH variation? These are some of the questions this lecture will try to answer using a survey of literature data, as well as the last experimental data acquired within the Centre Scientifique de Monaco using *Stylophora pistillata* as a model organism. Coral calcification is a highly-controlledcomplex process which mechanisms are only beginning to be understood.

Tuesday 10 July, 0830, Plenary Hall 2

Mission impossible: unlocking the secrets of larval fish dispersal on coral reefs

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One of the enduring mysteries in marine biology is how far larvae disperse away from their natal populations. The fate of offspring has remained a secret because of the seemingly impossible task of tagging tiny eggs and larvae. Our superficial knowledge of dispersal has fuelled controversies over how marine populations are regulated, and how marine populations should be managed for conservation and sustaining fisheries. In this seminar, I review for coral reef fishes - the historical debate, the contemporary dilemma and the emerging resolution. On behalf of many collaborators, I recount our 15yr mission to measure larval dispersal by detecting parent-offspring relationships using chemical tags and DNA. We began with some of the smallest of reef fishes (clownfish), but have since expanded our work to include some of the largest (coral trout, groupers). The unfolding story for all species is a tale of two extremes - from juveniles that have found their way home, to others that have crossed >100km of open water, and found a home away from home. We hypothesize that this 2-tailed dispersal strategy promotes population resilience, as natal homing contributes to local persistence, while long-distance dispersal contributes to population recovery. It means that networks of marine reserves can achieve both conservation and sustainable fishing objectives, as reserve populations will retain some of their progeny, while others will be spread to areas open to fishing and to other reserves. We argue for pluralism in the management of coral reef fishes, as they have been confronted with many problems, and their innate dispersal abilities offer a range of solutions.

Tuesday 10 July, 1400, Plenary Hall 2

Corals: Resilient or fragile and how it matters to management?

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There is no question corals are suffering from an onslaught of threats, ranging from bleaching, to blast-fishing, to invasive species. Some worry we may soon have a world without coral. Clearly there are management and human actions and policies that can make a difference. Scientifically what is needed is a steel-eyed look at what are the best prospects for getting through these depredations, and the extent to which, if stresses are relieved, some manner of coral diversity and function can be maintained. I will report the results of a meta-analysis on coral damage and recovery with special attention given to policy and management implications.

Wednesday 11 July, 0830, Plenary Hall 2

Conserving coral reef megafauna: Issues of ecological process, biodiversity, cultural diversity and food security

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Megafauna including seabirds, sea turtles, marine mammals and elasmobranchs are key components of coral reef ecosystems and critical to many associated ecological processes. Most species are long-lived and slow breeding with a low maximum rate of increase; very high adult survivorship is generally essential for population maintenance. Despite legal protection, many populations have declined in recent decades and are listed as threatened by the IUCN. In many countries, conservation is seen as clashing with food security and the development associated with rapid human population increase. Here the challenge of conservation is a consequence of some of the world's major environmental problems: human population increase, the movement of peoples to coastal areas, habitat destruction and climate change. Many species are of high cultural value and some peoples regard them as central to their cultural identity. Hunting of some species is widespread despite being illegal in most range states. Most large animals caught incidentally in fisheries are killed because they represent several months' income to an impoverished fisher. Enough generic knowledge has accumulated about the biology of most coral reef megafauna and the threats to their populations for governments to take effective steps toward their conservation, if the political will and capacity exist to do so. Legal protection and MPAs are not enough. Conserving marine megafauna will require culturally-appropriate solutions that address food security in the face of climate change and convince individual stakeholders, particularly fishers, that these animals are worth more alive than dead.

Thursday 12 July, 0830, Plenary Hall 2

Can old corals learn new tricks?

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One of the main challenges for today's reef corals is to keep up with the pace of climate change. Increases in temperature have already led to a reduction in coral cover and diversity. Unless corals can adapt, further losses of coral extent and diversity is expected to occur over the next decades. In this seminar, I will discuss some of the main attributes that provide the coral animal and its microbial symbionts with the potential to respond and adapt to climate change, as well as some of the

intervention measures that might be considered to assist corals to adapt to climate change.

Thursday 12 July, 1400, Plenary Hall 2

The future of corals and coral reefs in a rapidly changing world

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The severe consequences for corals of accelerated global warming and ocean acidification have led many to predict that coral reefs are doomed. Projected increases in the burning of fossil fuels will raise sea surface temperatures and pCO_2 by 2100 to levels that exceed known abilities of corals to survive. Adaptation to such rapidly changing conditions is questionable, although genetic variability is great and the selection pressure enormous. Stringent limits on fishing and pollution increase resilience of protected compared to unprotected reefs, but are unlikely to be effective against average increases in temperature of 3-4^{o}C and comparably severe acidification. However, corals will not be the only victims of climate change. Extreme drought, agricultural failure, intensification of storms, and unstoppable sea level rise of at least 1 meter will uproot one third of humanity and disrupt social order and economic growth to such an extent that mass starvation, pandemics, and chronic conflict appear as inevitable as the demise of coral reefs. Thus the big question for corals is whether climate change will get us first, or even better we wake up in time to save ourselves. Either way, there is a great deal that people can do for reefs today through local actions to stave off the immediate effects of climate change, as well asbuy time towards a hopefully more positive future for both corals and a chastened but wiserhumanity.

Friday 13 July, 0900, Plenary Hall 2

Coral reefs and global change: Where do the solutions lie?

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The scientific consensus that Earth's climate is changing rapidly, with no recent precedent, is undeniable. Current conditions exceed those of the last million years, with projected changes taking us beyond those seen for 40 million years. Withinthe developing crisis, coral reefs have been the colourful 'poster child' of ecosystem impacts, illustrating strong traceable linkages between climate change, ecosystem changes, and dependent human communities. Projected changes are also largely unambiguous in broad terms. Sea temperatures that triggered the mass mortality of corals over the past 20 years are very likely to increase as global temperature escalates, probably exacerbated by increasing ocean acidification. While some coral communities may become more temperature tolerant through the loss of sensitive individuals and species, evidence for 'turbo-charged' evolutionary processes that will ensure the maintenance of the abundance, biodiversity and the carbonate balance of coral reefs is illusive at best. Consequently, most projections conclude that corals will be rare on tropical reef systems by mid to late this century. Beyond this, our knowledge islimited with many questions remaining (e.g. interactions between global/local stresses, response strategies). One tricky question is whether or not current efforts 'on the ground' to respond to rapid climate change have any chance of succeeding given the enormous geographic scale and complexity of the changes that are occurring. Related to this is how we balance the allocation of resources between building ecosystem resilience to climate change ('adaptation' in the IPCC parlance) versus assigning resources to an all-out-effort to solve the core mitigation issue, that of reducing CO_2 emissions from fossil fuels and land-use change.It is likely that these questions will trigger considerable robust debate.

Friday 13 July, 1515, Plenary Hall 2

Theme 1. Reefs through time

1A Reef & reef island geomorphology

Influence of reef geometry on wave attenuation in a Brazilian coral reef

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This study presents data from field experiments that focus on the influence of coral reef geometry on wave transformation along the Metropolitan Center of Recife MCR (Northeast coast, Brazil). First, a high resolution bathymetric survey was conducted, revealing a submerged reef bank 18km long and 1km wide, parallel to the coastline, with a quasi-horizontal top that varies from 0.5-4m in depth at low tides. Cluster similarity between 180 reef transects showed that in 75% of the area, the reef geometry presents a configuration similar to a platform reef (group.1), whereas on 25% of the area (group.2) it resembles a fringing reef. Measurements of wave pressure fluctuations were made at two stations (experiments 1 and 2) across the reef transect. Transmitted wave height variations, at a time scale of 6h with a well-defined 24h cycle, are evident at both experiments suggesting tidal modulation. Up to 60% (exp.1) and 90% (exp.2) of incident wave energy is attenuated by the reef top at low tides. This tidal modulation is most apparent in exp.2, due to reef geometry. At this station, the reef top is only about 0.5m deep during the MLSW, and almost all incident waves break on the reef edge. In exp.1, the reef top depth is 4m and waves with height ratios smaller than the critical breaking limit are free to pass onto the reef, being mainly attenuated by bottom friction. These results highlight the importance of reef geometry in controlling wave characteristics along MCR beaches.

1A Reef & reef island geomorphology
Wednesday 11 July, 1030, Sebel Tully

Morphodynamic response of reef islands to climate change: the importance of benthic foraminifera

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Coral reef islands are one of the most vulnerable landforms to climate change and sea level rise owing to low elevations, readily transportable unconsolidated sands, and dependence on a sediment supply derived from reef organisms that are sensitive to environmental changes (e.g. ocean temperatures and chemistry). Since reef island accumulation is dependent on this ecologically-driven sediment supply, time-lags between reef-flat sediment production and subsequent island accumulation are fundamental to predicting future island resilience yet remain poorly quantified. This paper presents the results of a high-resolution temporal and spatial study of transport-pathways that link reef sediment production and deposition. We provide strong evidence that reef islands with a contemporary sediment supply dominated by large benthic foraminifera (LBF) will respond first to near-future climate change. An example is given for Raine Island, a setting that provides a good environmental analogue for many reef islands of the Indo-Pacific. Reef-flat production of LBF and island beach accumulation is tightly coupled with extremely short temporal lags of less than 25 years while >80% of LBF on the reef-flat are very young (median age: 9 yrs). Taphonomic analysis indicates a statistical relationship between shell condition and age and thus a minimal amount of vertical sediment mixing as LBF are rapidly transported across the reef-flat. This study highlights the importance of LBF to island resilience in the near-future and indicates that ecological shifts that drive changes in sediment production by LBF will likely be a more rapid and critical control on island change than rising sea level.

1A Reef & reef island geomorphology
Wednesday 11 July, 1130, Sebel Tully

Simulating SLR and increased wave activity influence on reef accretion

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Coral reefs are unique in their ability to precipitate calcium carbonate from seawater at a sufficient rate to keep pace with a rising sea, and to consolidate this into a three-dimensional platform. Reef platforms underpin food security, tourism, employment and protection of the shoreline yet their integrity is threatened because of rising atmospheric CO_2 concentrations, which induce sea-level rise and intensify hydrodynamic forcing. This paper uses a combination of remote sensing, *in-situ* measurement of biophysical parameters and mathematical scaling techniques to model and compare the influence of these environmental changes on carbonate production at Lizard Island and One Tree Island on the Great Barrier Reef. Anticipated sea-level rise scenarios are superimposed onto the existing bathymetric profile of the case study sites to assess how the platforms will respond to anticipated changes in water depth given the current configuration of benthic cover and associated spatial variability in accretion rates. In addition to this, wave activity is quantified at the landscape scale and compared to local measures of carbonate production along spatial gradients to establish an empirical relationship between the two. Reef platform responses to both sea-level rise and

increased wave activity are simulated for the period 2010-2100 at both case study sites to compare the geomorphic response of continental and reef islands on the Great Barrier Reef to environmental change.

1A Reef & reef island geomorphology
Wednesday 11 July, 1040, Sebel Tully

Determining back-reef sediment transport using linear wave theory

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The geomorphology of coral reefs is directly influenced by hydrodynamic forcing. Yet there is a paucity of research regarding the processes involved in the transport and deposition of reef sediment. This has led to a confusion over the main forcing mechanisms that drive geomorphic evolution and sediment transport, with many studies referring to reef systems as 'event based', driven mainly by cyclonic or high energy events. There have been very few studies that measure *in situ* processes to determine the veracity of this assumption. This paper presents an initial assessment of sediment transport on a coral reef. Two days of wave and current data were gathered in three locations on a back-reef sand apron during modal wave conditions. Sediment entrainment was determined on a wave-by-wave basis using linear (Airy) wave orbital velocities and bed shear stress. The current direction when sediment was entrained was used to establish the direction of transport once sediment motion was initiated. Results show directional trends of sediment transport that correspond to the sand apron geomorphology. Sediment is generally transported lagoon-ward while some sediment is transported towards the reef platform. This occurs on the flanks of the sand apron where there is either an influence of channel-like formations or greater attenuation of wave energy. This result indicates that sand aprons have more complex sediment transport patterns than simply continual progradational sand transport, with similarities to other complex systems in siliciclastic environments such as deltas and washovers.

1A Reef & reef island geomorphology
Wednesday 11 July, 1250, Sebel Tully

Holocene development of an atoll-rim reef in the Maldives

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We observed Holocene reef structure and processes of formation at North Malé Atoll, Maldives, with observations from drilled cores and of submarine exposed reef interior along an ocean-lagoon transect across the atoll rim. The 53.5m coring was conducted on the southeastern part of Malé Island where former reef crest lies under reclaimed land. Five reef units were defined based on lithofacies of the core. Each reef unit contained coralline algal bindstone accumulated above loose reef sediments. The top unit is the post-glacial reef; the others are the Pleistocene reefs. The post-glacial reef is around 8m thick with coralline algal bindstone forming the uppermost 3.3m. The post-glacial reef structure was also observed on a lagoon slope of the northeastern Malé Reef where a reef failure exposed the reef interior, consisting of the post-glacial reef, down to 25m. The rigid reef structure was observed over the upper 2m of the lagoon slope. The antecedent atoll-rim topography of the post-glacial reef is shallower at the rim and deeper along the lagoon of the North Malé Atoll. Accelerator mass spectrometry dating of the coral/algal samples shows the development of the atoll-rim reef after 8 ka. The upward reef growth in the early to middle Holocene kept pace with sea-level rise at the seaward and lagoonward edges, which reached sea level around 6 ka. The additional upward reef growth observed in the core from the seaward edge indicates the middle-Holocene sea-level highstand in the Maldives.

1A Reef & reef island geomorphology
Wednesday 11 July, 1145, Sebel Tully

Reefs islands on the move: resolving centennial-scale morphodynamics of islands in Funafuti Atoll, Tuvalu

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The geomorphic stability of low-lying coral reef islands in response to sea level rise is an issue of international significance. However, scientific understanding of the modes, magnitudes and rates of geomorphic change of reef islands over decadal to century timescales is poorly resolved. This study presents the first centennial-scale analysis of geomorphic behaviour of reef islands from the atoll of Funafuti, Tuvalu, in the central Pacific Ocean. Using a combination of detailed island surveys from 1896, historical aerial photography, satellite images and GPS surveys this study presents a quantitative analysis of physical changes in 28 islands in

Funafuti that span a 114 year period. Results show that the majority of islands remained stable or increased in area over the timeframe of analysis (75%), with 25% of islands exhibiting net reduction in island area. Most islands exhibited large gross changes, which were expressed through adjustments in the planform configuration and position of islands on reef platforms. Modes of island change included: ocean shoreline displacement toward the lagoon; lagoon shoreline progradation; and, extension of the ends of elongate islands. The study highlights spatial variations in the net and planform changes in islands, which are related to exposure on the atoll rim and sedimentary composition. Results challenge existing paradigms of island geomorphic response and have significant implications for the consideration of island stability under ongoing sea level rise.

1A Reef & reef island geomorphology
Wednesday 11 July, 1245, Sebel Tully

Beach development on a high carbonate island, Niue, Pacific Ocean

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Beaches developed on coral reefs are considered to be some of the most vulnerable landforms to sea level rise, with their low elevation cited as the primary reason for this vulnerability. High islands are thought to be more resilient to climate change, yet the vulnerability of the beaches developed on them is less well understood. This paper focuses on the high island of Niue, SW Pacific, which is a raised atoll of Miocene age. Erosional terraces characterise the outer margins of the island, the lowest forming close to mean sea level. Beaches are found in small pockets at the rear of the lowest terrace with sediment accumulation appearing to be influenced by the width of the shore platform fronting the beaches and length of the embayment they are contained within. The island's beaches are also dynamic often being eroded during tropical cyclone events. In calm periods sediment readily accumulates within bays with the beach profiles maintaining a relative similar morphology over several years. The development of beaches is also closely related to the benthic communities that colonise the platform surface on which they are formed. Sediment composition is highly variable with various species of foraminifera accounting for over 80% of beach sand on the NW coast of the island to <10% in other locations. It therefore appears that the stability of the beaches is a function both of the ability of surrounding benthic communities to supply sediment as well as the level of wave energy dissipation across the shore platform.

1A Reef & reef island geomorphology
Wednesday 11 July, 1230, Sebel Tully

Hydrodynamic process controls on reef platform sedimentation

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Coral reef islands are wave coherent accumulations of carbonate sand and gravel deposited on reef platform surfaces. Recent studies have shown that platform shape crucially controls the focussing and convergence of waves and hence the conveyance and deposition of sediment on and around platform structures. A logical inference from this analysis is that platform reefs exhibit morphological characteristics which can be attributed to the presence of hydrodynamic forcing gradients across reef surfaces. This study presents data of hydrodynamic measurements, bathymetric surveys and sediment analyses conducted on multiple lagoonal patch reefs in the Maldives. Results indicate that platforms exhibit distinctive hydrodynamic process signatures, related to platform configuration, which control sedimentation processes and the deposition of detritus on and around the structures. Accordingly, sediment is more likely to be contained on platforms which feature marked wave convergence behaviour such as elliptical shaped reefs. Conversely, linear platforms are more likely to promote the off-reef evacuation of sediment over leeward reef margins and the subsequent infill of deeper lagoonal areas. Results demonstrate that hydrodynamic forcing controls spatial variations in sediment deposition and therefore surface morphology of platform reefs. The study provides field evidence for theoretical predictions of reef sedimentation and has significant implications for the formation and morphological development of reef platform deposits.

1A Reef & reef island geomorphology
Wednesday 11 July, 1035, Sebel Tully

Sediment flux and off-reef export on the Vabbinfaru reef platform, North Malé Atoll, Maldives

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Reef platform sediment dynamics provide an important control on the morphology and development of reef systems and their sedimentary deposits by actively removing and redistributing sediments. This study presents one of the first detrital sediment budgets for a reef platform in North Malé Atoll, Maldives. The rate and magnitude of off-reef export and platform surface sediment transport were assessed experimentally using a suite of sediment traps. A large rubble trap and sand trap were attached to the reef slope (~ 6 m depth) at 8 sites around the island periphery for a period of 13 months. Direct measurements of bedload sediment transport were collected at four locations on the reef platform using bi-directional traps. Sampling was conducted over two, three

week periods during both northeast and southwest monsoon seasons to account for variations in platform hydrodynamics. Sediment textural characteristics of trap material were established hydraulically. Results show that off-platform export rates were high, reaching a maximum of 12.58 kg/m/y for gravel-size sediment and 122.84 kg/m/y for sand-size material. However, export rates varied spatially and seasonally around the platform. It is estimated that a total of 127,120 kg/y is exported off the platform annually. Gross annual sediment transport on the platform surface ranged between 26 kg/m/y and 467 kg/m/y with the majority of transport occurring during the southwest monsoon as a result of an increased wave climate. Results are discussed in the context of reef platform and island geomorphic development, and linkages between contemporary reef production and sediment flux are explored.

1A Reef & reef island geomorphology
Wednesday 11 July, 1115, Sebel Tully

The complex reef of Rocas Atoll: conceptions of geomorphology, morphodynamics and sedimentology

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Located 266 km offshore of Brazil, the reef complex of Rocas is the only atoll in the South Atlantic. Two scientific expeditions to the Rocas atoll were aimed at developing a geomorphological map, a brief study of the morphodynamics of Farol Island and a sedimentary study on the reef complex of Rocas. With dimensions of 3.35 x 2.49 km, an 11 km estimated perimeter and an internal area of approximately 6.56 km², Rocas is considered one of the smaller atolls in the world. In its reef complex the following features can be observed: front reef; algal crest; proper reef; sedimentary deposit; tidepools, lagoon and sandy islands. Through former mappings done in Rocas, it was noticed that the Farol Island grew approximately 47,000 m² in 50 years. Farol island could be divided into three sectors: the Western sector, the portion of highest energy, the Northern sector, characterized by a strong coastal current, and the Eastern sector, characterized by low slope and medium sand fractions, indicating low energy. In the sedimentary environment, sand texture dominated. Mean grain size ranged from -1.23 to 2.34ø, (average, 0.69ø), which represents a high-energy environment, however, the values of mean size varied in the different geomorphologic compartments. Sorting ranged from very well sorted to poorly sorted (mean value, 0.97ø). Skewness ranged from negative to positive, where positive values were associated with environments of deposition. The kurtosis parameter showed little relevance in this study. The sedimentary particles are composed of eleven major groups, where coralline algae are the most remarkable.

1A Reef & reef island geomorphology
P001

Impacts of Cyclone Yasi on nearshore reefs of the Great Barrier Reef

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Yasi (Category 5) was a large (~700 km across) cyclone that crossed Australia's Queensland coast near Mission Beach on 3rd February, 2011. Yasi was among the most powerful recorded cyclones to have crossed the Queensland coast, with winds gusting to 285 km/h and wave heights exceeding 9m. Numerous nearshore coral reefs occur within the region affected by Yasi, but several in the immediate landfall path (King Reef, Lugger Shoal and Dunk Island), as well as more distally located reefs (such as Paluma Shoals in Halifax Bay to the south) have been the focus of recent (between 2006 to 2009) pre-Yasi studies into their geomorphology, sedimentology and community structure. Here we discuss data from a recent (August 2011) re-assessment of these reefs, which has provided a unique opportunity to undertake multi-proxy assessments of cyclone impacts on reefs that have often been assumed, due to their sediment-dominated and poorly lithified internal structures, to be susceptible to physical disturbance and reworking. Overall impacts on large scale reef geomorphology were relatively limited at all of the sites under investigation, and there is no evidence of major reef framework erosion. Ecological impacts were similarly restricted, with only localised coral toppling and breakage occurring. Thus whilst small-scale and taxa specific impacts from Yasi are evident, geomorphological change was minor and ecological impacts were patchy and probably of short duration. This has probably been as much a function of contemporary evolutionary stage and ecological make-up, as physical location and exposure.

1A Reef & reef island geomorphology
Wednesday 11 July, 0930, Sebel Tully

Quaternary influence on the contemporary habitats of Cay Sal, Bahamas

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The Bahama Archipelago consists of an arcuate chain of carbonate platforms, commonly capped with low islands, separated by deep inter- or intra-platform basins. Average water depths on the platform tops, such as the Great Bahama Bank (GBB), are typically 10 m or less with thick sediment accumulations and the frequent occurrence of islands. There are however notable excursions from this depositional motif. For example Cay Sal, a little studied detached carbonate bank with depths ranging from 9-16 m, is only slightly deeper than the GBB, but devoid of islands and holds little sediment on the platform top. Obscured by only a thin sand veneer, the topography of the Pleistocene bank-top is easily examined. Through a combination of satellite imaging, aerial photography, vessel-based and SCUBA observations, we map Cay Sal's karstified and scoured bedrock to examine the influence of pre-existing topography on today's benthos. Coupled with interpretation of acoustic soundings and sub-bottom profiles, we show how karst depressions control the placement and geometry of sand sheets and seagrass meadows. Bank-top reefs accentuate the lines of submerged Pleistocene aeolianite dunes. Acoustic profiles of the bank's flanks reveal several episodes of abandoned reef development and offer insight as to the Holocene sea-level history of Cay Sal. We show how sea-level rise, particularly with respect to changes in rate of rise, has acted as a control on sedimentation on the platform and how subaerial processes throughout the Pleistocene have delivered antecedent topography that strongly directs the modern arrangement of benthic habitats.

1A Reef & reef island geomorphology
Wednesday 11 July, 1215, Sebel Tully

Geomorphic impacts of November 2008 wave event on Nukatoa, PNG

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Beginning on the 10th of December 2008 the isolated atoll of Takuu, located approximately 300 km to the north east of Bougainville, was affected by three days of large waves at a time coinciding with high spring tides and water levels elevated by ENSO set-up in the Western Pacific. During this event, waves washed across the small (<3 ha) reef island of Nukatoa, which is located on the northeastern rim of the atoll and is home to approximately 600 people. GPS shoreline mapping and topographic surveys of the island were undertaken in the days immediately prior to the event, and were repeated immediately after. This event, which was generated by two distant storms and affected a large area of the Western Pacific, produced a range of geomorphic impacts including shoreline reconfigurations and, most significantly, the deposition of an extensive sand sheet up to 20 cm thick across some parts of the island. In this talk the nature and significance of the event and changes will be presented and discussed.

1A Reef & reef island geomorphology
Wednesday 11 July, 1000, Sebel Tully

Sediment mixing depth in sand aprons in coral reef environments

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Sand aprons are ubiquitous features of coral reef environments yet there are very few studies that attempt to understand the sediment transport processes that drive their progradation. It is known that waves and currents are the main forcing mechanisms and it is commonly assumed that these features are event driven and hence only undergo change during high energy conditions. This paper presents data from One Tree Island (Southern Great Barrier Reef, Australia) which is exposed to ocean waves and has a well developed apron on its southern flank. Studies on the decadal evolution of the apron were undertaken using GIS; images (aerial and satellite) from 1970 and 2009. Additionally, an intensive fieldwork campaign was undertaken in 2011 where currents and waves were simultaneously measured at three stations across the apron. Sediment transport was measured through mixing depth profiles at each station and using two Optical Backscatter Sensors (OBSs) at one station. Wave transformation across the reef flat and sand apron was measured near the OBSs with 10 pressure transducers (10 Hz). Preliminary results show that decadal scale changes are less than expected and that there are small but perceptible daily changes on the sand apron (average accretion of 1 cm) under 0.5 m waves during spring tides. These data appear to contradict common assumptions that suggest large changes occur over a period where several high energy events would have occurred and no changes would occur under modal conditions.

1A Reef & reef island geomorphology
Wednesday 11 July, 0945, Sebel Tully

A sediment-budget modelling approach to the geomorphology of reef islands

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Reef islands, perched on the perimeter of coral atolls or comprising small cays on the leeward margin of reef platforms, appear fragile and vulnerable to the vagaries of climate change, particularly sea-level rise. They are built, largely by wave activity, from the biogenic sediments that are

produced in the reef environments around them. Most reef islands appear small and low-lying, but there are subtle differences in island topography which result from their different histories of accretion. Most are dynamic, with patterns of shoreline change reflecting the various sediment sources and sediment sinks. Attempts to quantify the exchanges between these can only be poorly constrained by field measurements, but can be simulated using geospatial modelling. This paper explores these approaches and proposes a mapping and modelling framework by which segments of shorelines can be discriminated in terms of their geomorphology. Such an approach provides a basis for management of changeable processes, and seeks to enhance the natural resilience of reef islands, to increase their sustainability into the immediate future.

1A Reef & reef island geomorphology
Wednesday 11 July, 1015, Sebel Tully

Geomorphology and evolution of reef islands in New Caledonia

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We examined geomorphology, sediments, and Holocene evolution of reef islands in the southwest of New Caledonia. Reef islands are distributed mainly on platform reefs in the lagoon of Abore Barrier Reef. Two types of reef islands are found: shingle cays that are unvegetated and composed of coral shingle, and sand cays that are generally vegetated and composed mainly of foraminifera tests, which could be similar to the reef islands in the Great Barrier Reef of Australia. Dating fresh foraminifera tests in the core and surface sediments from one of the sand cays (Mba Island) revealed that the island core formed before ~4000 years BP at the leeward part of the platform reef. The island grew continuously toward the southeast. Late Holocene sea-level history was determined by fossil microatolls found at another sand cay close to Mba Island. They showed 1m higher stable sea level than that at the present, before 2700 years BP. Our study demonstrates that reef-island evolution occurred under stable but higher sea level than that at the present, and relative sea-level fall after 2700 years BP may have had little impact on the evolution. This study was supported by the ANR INTERFACE program and JSPS Postdoctoral Fellowship for Research Abroad.

1A Reef & reef island geomorphology
Wednesday 11 July, 1200, Sebel Tully

1B Reef response to sea-level & environmental changes

Lithostratigraphic reconstruction in coral sequences, IODP Expeditions 310 and 325

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Hard rock formations such as carbonates and specifically corals with complex architecture, can be challenging to core, hence, recovery rates are often low. However, by combining information obtained on cores with in situ, continuous wireline logging measurements a more complete interpretation of overall stratigraphy is possible. We examined downhole measurements looking for specific trends in the data that relate to facies changes. Core-log integration is one of the principal objectives of any IODP expedition to better constrain depth of cores collected using a continuous dataset. Here we integrate the downhole measurements with sedimentological descriptions on cores and core digital line scans, to relate formation physical properties to recovered facies. Acoustic and Image logs can provide detailed information on coral species and a clearer picture on how much of the formation has been recovered, compared with void space. They also have the potential to record facies changes that are not observed in core or are simply unrecovered. For example, the wireline data and images collected in Hole M0054B (IODP Expedition 325 - GBREC) record a major environmental change/boundary in situ. These data can then be linked to the core material and aid in placing the recovered corals at their true depths. In order to examine trends in the data more objectively, the downhole measurements were also analyzed using an Iterative Non-hierarchical Cluster Analysis (INCA) program. The program starts with k random clusters, and then moves objects between those clusters aiming to (1) minimize variability within clusters and (2) maximize variability between clusters.

1B Reef response to sea-level & environmental changes
P002

Seismic profiling survey on submerged coral reefs south off Okinawa Island in the northwestern Pacific

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Shallow seismic profiling surveys and bathymetric mapping were carried out around Okinawa Island, which is located in a central part of the Ryukyu

Island Arc. The Ryukyu Island Arc extends from Kyushu to Taiwan, a distance of 1,200 km, along the Ryukyu Trench where the Philippine Sea Plate is subducting beneath the Eurasian Plate. During three cruises of the geological survey of Japan (GH08, 09 and 10 cruises) south of Okinawa Island, we found mounds that are interpreted as submerged coral reefs. High-resolution seismic data were collected using 2800LLX (30 cu.inch) cluster gun with 16 channels digital streamer cable and parametric SBP (sub bottom profiler) system of TOPAS PS18. The survey lines ran in a NW to SE direction at approximately 2 mile intervals. Bathymetric surveys were conducted using a multibeam echosounder along the seismic survey lines. The images of the mounds shown on the reflector, which may represent erosional surfaces, formed in the last glacial period and are about 40m (0.055 sec TWT) high and 30-50 m wide. The Holocene stratified sediment onlapping overlies the reflector and modern topographic high reaches 15m. Mounds can found at about 140 m in water depth and the topographic profile is very similar to the modern one of reef crest to upper slope area (0-50 m in water depth). We conclude that the reefs couldn't catch up with abrupt sea level rise to form a crest, and maybe escapes to close areas of recent coral reef.

1B Reef response to sea-level & environmental changes
P003

Penultimate glacial tropical Pacific sea surface temperatures from Tahiti corals

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Fossil corals are an excellent archive for documenting changes in sea level and sea surface temperature in the past. Coupled determinations of Sr/Ca and oxygen isotope compositions in massive *Porites* corals enable the construction of ultrahigh-resolution time series for both sea surface temperature and salinity (e.g., Gagan et al., 1998, Felis et al., 2009). However, the distribution of fossil coral data is spatially and temporally limited, and biased toward periods of sea level highstands (interglacial periods), because most fossil reefs of glacial age are located today at water depths of >100 m (e.g., Bard et al., 1990; Lambeck and Chappell, 2001). In 2005, the Integrated Ocean Drilling Program (IODP) Expedition 310 (Tahiti Sea Level), conducted by the European Consortium for Ocean Research Drilling-Science Operator using the mission-specific platform (DP Hunter), drilled the coral reef system off Tahiti, French Polynesia (Camoin et al., 2007). We present bimonthly resolved Sr/Ca and oxygen isotope records from annually-banded skeletons of fossil *Porites* corals recovered during IODP Expedition 310. The samples are well preserved without evidence of diagenesis. The coral ages were determined by U/Th dating (Thomas et al., 2009). Our coral-based estimates of temperature and oxygen isotope composition of sea surface waters are a unique ultrahigh-resolution source of thermal and hydrologic variations for selected time windows of the penultimate glacial period, furthering our insight into past tropical South Pacific climate change and providing a reference for new results from IODP Expedition 325 (Great Barrier Reef Environmental Changes).

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1245, Sebel Tully

Diagenesis of the Great Barrier Reef during the last deglacial

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Diagenetic features are sensitive recorders of physical and chemical environmental changes in reef systems and are of prime importance to reconstructing fluid palaeocirculation and chemistry (e.g. pH, alkalinity, redox conditions and water temperature). The main objective of the IODP Expedition 325 was to unravel environmental changes on the Great Barrier Reef (GBR) since the Last Glacial Maximum, based on coral reef drilling. The first results demonstrate that reef development and architecture were strongly controlled by sea-level history during this time window (see Webster et al., this volume). This study focuses on the diagenetic evolution of the last deglacial reef carbonates and aims: (1) to establish the relative chronology of the diagenetic events, e.g. Fe and Mn oxides, microstalagmites, early dissolution and neomorphism, based on the integration of these events within the absolute time frame provided by the coral dating, especially during 'turn-on' and 'turn-off' episodes; 2) to determine the nature of fluids involved in the diagenetic history through the study of the mineralogical and geochemical composition of the various diagenetic features; Finally, the post-LGM diagenesis -purely marine- will be compared with the marine and meteoric pre-

LGM history to evaluate the impact of the various diagenetic processes on the petrophysical characters of reef carbonates.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1745, Sebel Tully

Coralline algae in Last Glacial Maximum and postglacial deposits in the Great Barrier Reef

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The Integrated Ocean Drilling Program (IODP) Expedition 325 drilled 34 holes across 17 sites in 4 transects across a series of drowned terraces along the shelf edge, from 129 to 40 m depth, in the Great Barrier Reef (GBR), Australia. The recovered materials mainly comprise Last Glacial Maximum (LGM) and post-glacial coral reef deposits, in which coralgal-microbialite and coralgal boundstones are the dominant lithologies, usually overlying unconsolidated bioclastic lime sand and pebbles. Crustose coralline algae (CCA) are common in the boundstones, partially coating corals and intergrown with vermetids, encrusting foraminifers and other invertebrates. The species of CCA recorded in the boundstones are living today in the GBR and other Indo-Pacific reef areas. Because some modern CCA species live in relatively narrow depth ranges, their modern distributions can be used for interpreting the palaeodepth of the fossil reef deposits in which they occur. In each successive terrace upslope, the pervasive occurrence of thick crusts of Hydrolithon onkodes in the boundstones indicates that LGM and postglacial reefs in the GBR grew in shallow water, aggrading a few tens of metres. Continued sea-level rise then drowned the reefs which are capped by thin deposits with mesophotic (deeper-water) CCA assemblages (such as *Mesophyllum funafutiense*, *Hydrolithon reinboldii* and *Lithophyllum* spp.), followed in some holes by deposits of deeper lime sand or mud.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1000, Sebel Tully

Reef growth in inshore terrigenous sedimentary settings on the Great Barrier Reef

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Reef growth in inshore terrigenous sedimentary settings on the Great Barrier Reef is the product of both carbonate production and accumulation, and terrigenous sediment deposition. Traditionally, high sediment loads are associated with reduced carbonate production due to the associated negative effects of sediments both deposited on the reef, resulting in the burial of reef benthos, or in suspension, reducing light availability. However, the lack of quantitative data on terrigenous sediment input and flux rates, and on carbonate production rates has inhibited understanding of both ecological timescale rates of carbonate production and the aggregated long-term net impacts of sediments on reef growth. To address this knowledge gap a carbonate budget and terrigenous sediment model, that quantified sediment inputs onto and off reef, was developed at two inshore reefs: Middle Reef and Paluma Shoals. The average reef accretion rates estimated from net carbonate productivity on Middle Reef and Paluma Shoals was 5.3 mm/year and 3.0 mm/year respectively, with hindcast projections suggesting that reef initiation occurred approximately 790 yr BP at Middle Reef and ~1,190 yr BP at Paluma Shoals. These reef initiation estimates are remarkably similar to dates obtained from radiometric dating of reef cores, which suggests that net carbonate production rates and, therefore, coral community composition, have been relatively stable since reef initiation despite recent anthropogenic activities. The hindcast growth models quantitatively links sedimentary processes to ecological processes, and can be used to assess how reef growth may respond to future environmental changes such as increased sediment delivery and rising sea-level.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1115, Sebel Tully

Coral reef response to sea level change, western Australia

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The western margin of Australia provides a regional latitudinal and climatic gradient from the macrotidal tropical north to the microtidal temperate south, modulated by the poleward flowing warm Leeuwin Current. Coral reef systems vary from fringing reefs to isolated reefs which rise from deep-ramp settings. The well-constrained sea level data from the Houtman Abrolhos carbonate platforms (at 28-29°S) have also been applied to the less known North West Shelf reefs. The Ningaloo fringing reef at 20-22°S records Holocene and last interglacial phases of reef growth in a tectonically stable environment. Scott Reef (at 14°S) is a macrotidal, isolated reef which overlies a carbonate platform and a major gas discovery. Seismic profiles reveal a last interglacial (ca. 125,000 year) reef system, but reefs which apparently grew to sea level are 30 m

below present sea level, indicating significant subsidence in the Late Quaternary. Contemporary reefs grew during the Holocene in the accommodation provided by subsidence and are up to 35 m thick. The Rowley Shoals (15-17°S) comprise one of the most perfect morphological series of reefs known, and these emergent, annular reefs rise from depths of 200-400 m. Seismic profiles suggest Late Quaternary subsidence has been an important control on reef growth, while differential subsidence has influenced reef morphology. Differential geomorphic and physical process settings, seismic stratigraphy, sea level history, and subsidence are keys to patterns of reef growth which can be seen as responses to these controls.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1145, Sebel Tully

Sea-level induced sea-floor morphologies, Malé Island/Goidhoo Atoll, Republic of Maldives

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A 2008 high resolution multi-beam survey around Malé Island, using a Kongsberg Simrad EM 3000 and commissioned by the Republic of Maldives, clearly images a series of individual morphological features. The lagoon seafloor, typically between 40-60 mbsl, shows numerous enclosed and unfilled round-to-oval depressions, 10-to-200 m in diameter, lined-up along fractures. This typical karst morphology testifies that the North Malé Atoll lagoon floor was once an exposed limestone plateau, when sea-level had fallen below 40-to-60 mbsl. A recent seismic survey of Goidhoo, a classic atoll with a reef rim fully enclosing a lagoon, shows that the flat-floor, at ~40 mbsl in such lagoons, is the result of burial of well-developed karst morphologies, such as the one observed in North Malé atoll, by Holocene sediment. The Malé Island southern margin displays, between 40-150 mbsl, a series of slope terraces separated by distinct steps. A narrow terrace between 105-115 m, individualized by two well-developed cliffs between 115-125 m and 95-105 m, probably correspond to the locations of Last Glacial Maximum (LGM) and Oldest Dryas coastlines. Further up the slope, a series of shallow steps and terraces are linked to the well-established stepwise sea level rise (Melt-Water-Pulses) during last deglaciation. Along Malé Island western margin, a series of prominent, up to 6-to-8 m deep, and discontinuous notches, systematically observed at water depths between 21-26 m, are interpreted to represent older shorelines when sea-level had dropped by ~20 m along a partially exposed coralgal edifice accumulated during the last interglacial Marine Isotope Stage 5e.

1B Reef response to sea-level & environmental changes
P004

Geographic variation in Holocene Pacific island reef accretion rates

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To facilitate modelling of reef accretion under changing environmental conditions, we carried out a geographic analysis of Late Pleistocene and Holocene reef accretion rates on non-continental islands of the Pacific, relating reef accretion rates through time to sea level and environmental conditions. Reef accretion rates were determined from 65 cores from 33 localities, limited to curves with 3 or more ages, using calibrated radiocarbon or U/Th ages. Instantaneous accretion rates were calculated for each 1000 year-period between 15ka and Recent using linear regression or logistic curve-fitting. Accretion rates were compared among time slices, regions, reef types and facies, and along gradients of age, latitude, temperature, average wave height, storm frequency, and nutrients. Regional sea level curves were derived from the ICE-5G model. Most reefs cored were catch-up reefs. Accretion rates were positively correlated with median age, decreasing to < 3 m/ky in cores younger than 3 ka. Accretion rates were lowest in the northeast (Hawaii) and northwest Pacific (Palau, Guam, Ryuku islands), and were weakly inversely correlated with absolute latitude. Atoll accretion rates were all < 6 m/ky; fringing reef, mostly < 6 m/ky, except for some lagoonal sequences. Barrier reef accretion rates ranged from <1 to >11 m/ky. Highest accretion rates were from keep-up reefs of Tahiti and Papua New Guinea. Accretion rates were weakly negatively correlated with increasing tropical storm frequency, and were higher in areas with higher average wave height, but accretion rates were not significantly different among reef facies or between windward and leeward aspects.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1200, Sebel Tully

Last deglacial tropical Pacific sea surface temperatures from Tahiti corals

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Coral Sr/Ca-based reconstructions have revealed a larger amplitude sea surface temperature (SST) change throughout the last deglaciation compared to foraminiferal Mg/Ca and alkenone-based SST reconstructions, both in the tropical Atlantic and tropical southwestern Pacific. Here we present new coral Sr/Ca records from Tahiti in the central tropical South Pacific derived from fossil *Porites* sp. colonies drilled by Integrated Ocean Drilling Program (IODP) Expedition 310. These corals provide subseasonally resolved snapshots of tropical Pacific climate during the last deglaciation, accurately dated by U-series. We use (1) several living *Porites* colonies as a robust modern benchmark to take into account between-colony offsets in mean Sr/Ca of modern Tahiti *Porites* corals, (2) a thorough diagenetic screening procedure, and (3) a common aragonite standard to correct for inter-laboratory offsets in mean Sr/Ca. Based on this approach we conclude that early Holocene SST was not significantly lower than today and that early last deglacial SST was not lower by several degrees relative to modern SST in this region of the tropical Pacific, as reported in some earlier coral Sr/Ca-based reconstructions from tropical oceans. However, our results indicate a significant cooling during the Younger Dryas consistent with earlier results from Vanuatu in the western tropical South Pacific. Moreover, a monthly resolved coral Sr/Ca record from 15.0 kyr ago reveals pronounced interannual variability at typical El Nino-Southern Oscillation (ENSO) periods, suggesting that ENSO was active during a time interval of intense North Atlantic cooling and weakened Atlantic meridional overturning circulation known as Heinrich Stadial 1.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1215, Sebel Tully

Earthquake supercycle terminations in Sumatra over the last 5,500 years

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The nature of catastrophic earthquakes, such as the 2004 and 2005 events in west Sumatra, is not well understood, largely because the recurrence intervals of great earthquakes are difficult to document. Raised coral reefs preserved above the Sumatran megathrust, mark vertical crustal deformation during great earthquakes back to at least 7,000 years ago. Our team has discovered that carbon-isotope ratios ($^{13}C/^{12}C$) in the skeletons of well-preserved *Porites* corals record the sequence of crustal deformation leading-up to earthquake supercycle terminations. In 2009 we drilled corals living along the coast of Nias, offshore of western Sumatra, that were raised by up to 2.8 m during the Easter Monday March 2005 earthquake. The records show that $^{13}C/^{12}C$ in the coral skeletons is sensitive to the increase in ambient light intensity brought about when the corals rose to shallower water during co-seismic uplift. Given this encouraging result, we now have coral $^{13}C/^{12}C$ records showing the pattern of crustal deformation leading-up to three great earthquakes around 400, 2,000 and 5,500 years ago. In all three cases, there is a distinct deformation 'turning point' ~20-60 years before each earthquake, when long-term crustal submergence switches to crustal emergence. Our goal is to extend the coral $^{13}C/^{12}C$ record to see if the deformation turning point is a reliable precursor for earthquakes in Sumatra. If so, identification of this $^{13}C/^{12}C$ signal in corals living above the Sumatran megathrust would improve community awareness of their position within the earthquake supercycle and where a great earthquake may strike next.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1500, Sebel Tully

Late Quaternary upper-slope deepening (fining) upward sequences (Great Barrier Reef)

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A 41.4m-long sedimentary sequence was drilled at 172 mbsl in Hole 325-M0058A southeast of Cairns offshore the Great Barrier Reef (IODP 325 Expedition). This sequence is composed of three green, muddy sections intercalated with two distinct sandy intervals. In the muddy sections, characterized by lighter colors and lower magnetic susceptibility values, the coarse fraction is dominated by planktic foraminifera. The upper sand/grainstone section, at least 2m-thick, consists of fine-to-medium sand with large lithoclasts of well-cemented grainstone and visible fragments of mollusks, bryozoa, coralline algae, echinoids, 'larger' benthic foraminifera, and serpulids. The lower sand section is about 7m-thick and characterized by fine-to-medium sand. Carbonate and aragonite content values in bulk sediments cycle between 30-75% and 10-40%, respectively. XRD aragonite content variations correlate well with

strontium XRF counts. The lithological cycles, clearly observed in the sedimentary section, represent deepening (fining) upward sequences, corresponding to the last two and one half glacial-interglacial cycles from Marine Isotope Stage 7 to 1. This interpretation will be tested by planktic oxygen isotope records currently developed throughout the core at 10cm-spaced intervals. During glacial intervals, times of continental shelf exposure, the neritic factory migrated downslope shedding coarse carbonates that accumulated with siliciclastics at the Hole 58A location (~40 mbsl). Once the deglaciations were initiated, the coralgal reefs migrated westward and upward to keep up with the 120 m sea-level rise. Reef derived, fine aragonite and high Mg calcite sediments were then exported towards Hole 58A and mixed with pelagic particulates.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1530, Sebel Tully

Magnetostratigraphic constraints regrading the age of IODP 325 Hole M0058a

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We have studied the rock magnetic and paleomagnetic properties of a 41 meter-long core (Hole M0058A) recovering fine calcareous sediments located seaward of Noggin Reef, off Queensland, Australia of IODP Expedition 325, GBREC, to decipher the magnetostratigrapy of the site. We deployed 1-cc samples at every 10 cm down-core and we also subsampled the core by means of U-channels in order to obtain a continuous record of the directions and intensity. We have conducted stepwise Alternating Field demagnetization (AF) from NRM to 80 mT from 180 discrete samples as well as the U-channels. The characteristic remanent magnetization (ChRM) was isolated at low fields typically between 0-25 mT, indicative of magnetite as the primary carrier. In addition to the AF experiments we have conducted magnetic granulometry analyses and Curie point determinations of five specimens. The low-field susceptibility vs temperature (k-T) analyses indicate the presence of Ti-poor magnetite with Curie points from 560^{o} to 563^{o}C. Hysteresis loop experiments were carried out using a VFTB instrument. The results show Mrs/Ms and Bcr/Bc ratios corresponding to Single Domain to MultiDomain (SD-MD) ranges and Super paramagnetic (SP)-Single Domain (SD) (SP-PSD) ranges when compared to the theoretical mixing curves. The final magnetostratigraphic results revealed four anomalous directions occurring during intervals of low relative paleointensities (RPI) corresponding perhaps to the Laschamp (~41 ka), Skálamælifell (~94 ka) and Blake (~115-120 ka), “aborted reversals” indicating that the bottom of the site has to be much older than the Blake excursion.

1B Reef response to sea-level & environmental changes
P005

Seismic stratigraphy of the shelf edge of the Great Barrier Reef

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Understanding of the past development of the Great Barrier Reef (GBR) provides an important framework with which to better predict the future of modern carbonate systems, especially in response to abrupt climate changes. This study takes a seismic-stratigraphic approach and investigates the geomorphic response of the submerged GBR shelf edge reefs to past sea level and climate changes since the Last Glacial Maximum (LGM). Based on new high-resolution 2D seismic data (Topas, Sparker), constrained by other data sets (multibeam bathymetry, IODP Exp. 325 core and petrophysical data), we investigated the 3D architecture of the shelf edge at Hydrographers Passage. We identified three distinct seismic units, bounded by prominent reflectors, in sub-bottom profiles across the inner lagoon to the reef edge. Within each of these units, seismic facies were recognized based on signal elements such as clinoform associations, character (mute, chaotic, continuous), attributes (e.g. amplitudes), and reflector shape. These facies constitute the expression of specific depositional features (e.g. bedding patterns, reef growth, erosion, karst) and of the physical properties of the reef and associated sediments, and are fundamental to understanding the evolution of each broader seismic unit. The high density of seismic data at Hydrographers Passage allows for a 3D reconstruction of the system's architecture, and constitutes an important starting point for 3D numerical reef modelling. We present initial modelling results and discuss their broader implications for understanding the main geological and oceanographic processes that have influenced the evolution of the shelf edge since the LGM.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1040, Sebel Tully

Response of key coral species to Holocene sea-level change in the Western Indian Ocean

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The geological record of scleractinian corals is important for understanding reef ecosystems' response to climate change and anthropogenic stresses in the near future. Identifying the species that contribute to reef formation is of prime interest. Complementary investigations conducted on the Holocene drilling cores extracted from Mauritius Island (cores S1, S2, and S3) and Madagascar (cores TU-S1 and TU-S2) led to partial revisits of the regional reef growth and sea level histories. Biological and ecological analyses of the cores reveal that growth and maintenance of reef ecosystems were controlled by a few dominating coral forms (i.e., key species). In Mauritius, these include robust branching *Acropora* (*A. robusta/ A. abrotanoides, and A. digitifera*), *Isopora palifera*, and massive corals (*Platygyra daedalea*, *Favia stelligera*, *Cyphastrea*, and *Porites*). In Madagascar, Holocene reef accretion was predominantly governed by *Pocillopora eydouxi, A. robusta/ A. abrotanoides, I. palifera*, and *Favites chinensis*. The species composition is similar to that of the western Pacific reefs, and hence this result implies that Holocene reef accretion in the Indo-Pacific regions was controlled by a simple principle, although there is the biogeographical variation of species diversity in the regions. These findings indicate that a limited number of key species with high growth potential will be involved in the maintenance of the reef ecosystems during the global-scale sea-level rise in the near future. However, these corals are likely to experience mortality due to anthropogenic stresses, and thus this study emphasizes that the need for research into reef conservation and restoration with regard to key species.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1035, Sebel Tully

Sea-level rise versus Holocene reef accretion: who's winning the race

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The race between rising sea level and reef building was a focal point of the Fifth International Coral Reef Symposium in Tahiti. At that time, it was widely held that accretion rates of 10-14m/1000 years (m/ky) were common, making it difficult for healthy reefs to be outpaced by rising sea level. Nevertheless, the literature is replete with examples of reef drowning. Resolution of this paradox has involved either sudden jumps in sea level or dramatic reductions in water quality. Published data from 185 cores provide a global picture of reef building over the past 11,000 years. Accretion in 631 intervals in 185 cores was based on sample position in each core and age from U/Th or corrected ^{14}C. Average accretion rate by region ranged from 3.51m/ky in the Caribbean to 5.01m/ky in the Coral Sea. Only 7.8% of all reefs built at rates faster than 8m/ky (the nominal maximum for Holocene sea-level rise) and accretion rates below 4m/ky occurred in 60% of the cores. Reef drowning by normal marine transgression should be thought of as neither unusual nor paradoxical. While both sea-level jumps and inimical bottom waters have undoubtedly occurred, they are not needed to induce reef drowning. Looking forward, 51.1% of the surveyed reefs accreted more slowly than the present rate of sea-level rise (~3.2-3.5m/ky). This portends an anxious future for the world's coral reefs, especially when we consider that these rates reflect a time prior to any of the myriad stresses faced by reefs today.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1700, Sebel Tully

Changing coral assemblages since the Last Glacial Maximum: IODP Expedition 325

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Major goals of the Integrated Ocean Drilling Program (IODP) Expedition 325 (GBREC: Great Barrier Reef Environmental Changes) include reconstructing histories of sea-level change, sea surface temperature variation and reef growth since the Last Glacial Maximum (LGM), and analyzing responses of reef-building corals to post-glacial sea-level rise. Cores were extracted from submerged reef structures along four transects in three localities on the shelf margin, seaward of the modern Great Barrier Reef. 225m of drill-core were retrieved from 34 holes at 17 sites in depths from 42 to 167m below present sea level, and from 1.5 to 42m below the sea floor. Seven coral assemblages are defined, based on taxonomic and morphological compositions. Their paleoenvironments, by analogy with modern reefs, range from shallow wave-exposed to deep low-energy reef habitats. The initial post-glacial reef assemblage is dominated by shallow-water massive-submassive-branching *Isopora* with branching *Acropora* and thin branching *Seriatopora*. The deeper assemblages consist mainly of encrusting to submassive *Montipora* and encrusting Agariciidae. Horizontal differences between proximal and distal cores along transects probably reflect changing geomorphological and hydrodynamic regimes across the reef tract as sea level rose. Vertical changes in coral assemblages within a core reflect deepening of the water, leading to ultimate drowning of the coral community and creation of the tops of the submerged reef

structures. As sea level rose, shallow reef assemblages re-established further upslope and accumulated several meters of reef structure before drowning in turn.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1230, Sebel Tully

Advanced classification of carbonate sediments based on physical properties

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The Integrated Ocean Drilling Program Expeditions (IODP) 310 and 325 are the two more recent contributions to bettering our understanding of sea level changes. Carbonate sediment samples recovered during these expeditions can also provide a deeper understanding of coral reef responses to environmental changes. Physical properties such as gamma ray density, p-wave velocity, electrical resistivity, and magnetic susceptibility are related to characteristics of the marine sediments that, in turn, are indicative of the lithologic type. Non-destructive measurements can be taken using a Multi-Sensor Core Logger (MSCL) on whole core rounds, hence these data can assist with sample preservation and decisions about how the cores are split. The objective of this study is to model the relationship between physical properties and carbonate sediment types and to assess whether this approach can be used as a new rapid and accurate tool for classifying sediment types. Machine learning models can help to identify sample locations and core processing. The models are first trained with a partial, known data set and then tested against the larger, unknown data set in which predictions are made about carbonate sediment types present. The database and model integrate the sedimentologists observations with the physical properties data. All the data were analyzed with the software R by three different techniques: Linear Discriminant Analysis (LDA), Random Forest (RF) and, Support Vector Machines (SVM). Non-linear models better described the nature of the data exhibiting higher accuracy.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1750, Sebel Tully

Sea-level rise and the Lizard Island fringing reef

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Healthy fringing coral reefs are efficient attenuators of wave energy. Multiple stresses on coral habitats and a rising sea-level due to climate change may change local hydrodynamic conditions by reducing wave breaking and frictional dissipation around reefs. As a result, increased wave energy may occur across the reef flats, lagoons and previously protected shorelines. Recent studies in fringing coral reefs show elevated turbidity levels for coral reef habitats will increase in frequency and considerable coastal erosion might result even under a conservative 0.2 m sea-level rise scenario by the end of this century. A semi-empirical wave set-up and attenuation model was used to estimate changes in hydrodynamic condition under different wave conditions, distribution of habitats and sea-level rise scenarios. The model was based on detailed bathymetry, remote sensing-derived habitat maps and field measurements from the fringing reef system. Model results suggest that reefs are able to effectively absorb wave energy from episodic storms or cyclones, but increases in water depth over the reef caused by sea-level rise will result in more wave energy reaching the reef flat, lagoon and shoreline. The findings also highlight the importance of healthy corals and habitats such as seagrass meadows on reducing wave energy and water turbidity.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1030, Sebel Tully

Dominican Republic Drilling Project: a 2-myr record of Caribbean reefs

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The Dominican Republic Drilling Project (DRDP) was initiated in 2010 with the long-term goals of determining how Caribbean reefs changed over the past 2 million years. This period is marked by a number of biotic and environmental events including a protracted period of climatic deterioration (and probable cooling) between 2.0 and 1.0 Ma, the transition from 100 kyr to 41 kyr sea level cycles, and the turnover from reefs dominated by the genus *Stylophora* to those dominated by *Acropora*. A transect of five core borings taken along the southern coast (~250m total cored) was used to evaluate the series of stacked sigmoidal reef deposits that formed during repeated Plio-Pleistocene sea level highstands. Bounding surfaces identified in the five cores help define reef sigmoid geometries. Bounding surfaces were defined by subaerial exposure, abrupt textural changes, stable isotopic variations, and major changes in depth-indicative reef coral fauna. The

correlation of the main depositional packages is constrained by strontium-isotopic ages. New ages help to constrain deposits to within a resolution of two marine isotope stages, usually to within a range of 0.2 my in the Pleistocene. The stacking of these sigmoid-shaped reefs produced lateral progradation of approximately 15km. Eccentricity (high amplitude 100 kyr) sigmoids appear significantly different than obliquity (41 kyr) driven reef cycles, and may provide insights to faunal transitions.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1545, Sebel Tully

Quaternary atoll development: a numerical approach

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Based on previously published data from Mururoa Atoll and using two dimensional, process-based numerical modelling, an improved atoll development model is proposed for the last 1.8 Ma. Available field observations from coring indicate that, over the last 0.50 Ma, carbonate deposition at Mururoa Atoll has dominantly occurred along the outer rim forming a complex succession of stacked to rimming, high- to low- stand reef units. In a first step, a model therefore is designed to simulate the development of the atoll within the 0-0.50 Ma time interval. The observed atoll internal architecture over the last 0.50 Ma appears to be best explained using a subsidence rate of 0.075 mm/yr and an accumulation rate of 2.5 mm/yr. This model clearly indicates that constructional processes have played a dominant role in the present-day atoll configuration. In a second step, the atoll building history is investigated through the 1.8-0.50 Ma time range. The only reliable scenario accounting for the overall geometry of the foreslopes at Mururoa is the development of successive, gently-dipping ramp-like systems prior to 0.50 Ma. These systems are generated from carbonate accumulation rates less than 1 mm/yr. Lower carbonate production prior to 0.50 Ma is interpreted as resulting from environmental factors not conducive to reef growth. This interpretation is consistent with previous studies, strongly suggesting that only non-reefal communities have grown along carbonate-dominated ramps, not forming outer reef rims, in response to inimical climate conditions over the early to mid-Pleistocene.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1645, Sebel Tully

Volcaniclastics in coral reefs: evidence for disturbance and recovery (Middle Miocene, Austria)

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Volcanic disturbances and ecosystem recovery at sites of neritic carbonate production are rarely documented in the Recent as well as in the past geological record. We present a Middle Miocene (c. 14.5 Ma) shallow-marine carbonate record from the Styrian Basin (Austria) that shows recurrent breakdowns of the carbonate producers (i.e., coralline red algae, zooxanthellate corals) in response to ashfalls from nearby volcanic island sources. These volcanic events are preserved as distinct marl layers with idiomorphic biotite crystals and volcaniclasts that mantle the former seafloor topography. The pyroclastic sediments suffocated the carbonate producers in coral reef and seagrass environments. A subsequent turbid, eutrophic phase caused by the redistribution, suspension and dissolution of volcaniclastics is characterized by the spreading of suspension-feeding biota, coralline algae and the larger benthic foraminifer *Planostegina*. During this stage, rapidly consolidated pyroclastic deposits acted as hardgrounds for attached living bivalves. The fact that the facies below and above the studied ashbeds are almost identical suggests that volcaniclastic events had no long-lasting effects on the structure of the carbonate producing benthic communities. Although Miocene shallow-water carbonate systems of the circum-Mediterranean region are well known and situated in one of the geodynamically most active regions worldwide, this study is the first that exams the impact of volcanic sedimentation events on shallow-marine ecosystems.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1630, Sebel Tully

Low sea-level coral sequences from the Great Barrier Reef: IODP Expedition 325

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Late Quaternary coral reef assemblages and paleoclimates are known primarily from uplifted reefs formed under interglacial high sea-level conditions similar to the present. Assemblages associated with low sea levels during glacial maxima exist mainly as submerged fossil reefs on subsiding or tectonically stable coastlines, where most of them are now inaccessible. Such reefs have the potential to 1) generate novel information about the composition, environments, ecology, and growth of corals and coral reefs during glacial maxima, and 2) constraint knowledge of the magnitudes, timing and duration of Late Pleistocene climate changes and environmental conditions, and their impacts on coral reefs. IODP Expedition 325 (GBREC: Great Barrier Reef Environmental Changes) recovered cores from submerged fossil reefs along four transects across the shelf margin

seaward of the modern Great Barrier Reef (GBR). Preliminary U-Th and ^{14}C dating indicates ages span the last deglacial period, the Last Glacial Maximum (LGM), and the pre-LGM (>25 ka). Several cores contain pre-LGM coralgal boundstones, coralgal-microbial boundstones, and detrital deposits, and two cores contain sequences of distinct coral assemblages with different dominant taxa, including branching *Acropora*, encrusting to submassive *Montipora*, and encrusting Agariciidae. We provide descriptions of the pre-LGM coral sequences, interpret their implications for late Quaternary environmental changes, and compare them with core records from nearby modern GBR sites (Ribbon Reef 5, Boulder Reef) and with late Pleistocene material from the Huon Gulf, Papua New Guinea.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1015, Sebel Tully

Verification of paleodepth and island subsidence estimates, using imperfect U-Th data

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Uranium-thorium chronologies of corals drilled in offshore localities have provided valuable information on past sea levels; particularly from periods where sea level was considerably lower than present. In addition to earlier results from Barbados and the Huon Peninsular, results from uranium-thorium dating of corals recovered from IODP Expedition 310 'Tahiti Sea Level' have provided valuable information on the nature and timings of sea level rise across the past two deglaciations (20,000 to 6,000 and ~140,000 to 129,000 years ago). Older periods have been more elusive, due to the sparsity of available samples and diagenic alteration hampering accurate dating. Here, we present uranium-thorium chronology for a 102m core through a Pleistocene carbonate reef at Tahiti. We employ traditional as well as a partial dissolution sample preparation procedures to investigate diagenetic overprint of the uranium-thorium system. Combining the uranium-thorium data with stratigraphic and subsidence/sea level history constraints, approximate ages of corals are determined. We use these ages and, $\delta^{18}O$ based, sea level histories to provide constraints on possible paleo water-depths, which are then compared to depth estimates based on algal and foraminiferal assemblages and sedimentary facies, made in the absence of this chronological information. We confirm the accuracy of these paleo water-depth estimates. That corals could not have grown above sea level places a maximum constraint on the subsidence rate of Tahiti to be $0.39 mka^{-1}$, although paleo water-depth estimates for some of the older (undated) core sections suggest that the rate may be closer to the minimum estimate of $0.25 mka^{-1}$.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1730, Sebel Tully

U-series geochronology for the Last Glacial Maximum Great Barrier Reef

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The Great Barrier Reef (GBR) drilling project (IODP Exp. 325) was designed to complement existing deglacial records from Barbados and Tahiti, to establish the history of sea level and climate change before and during deglaciation, and to document the reefs responses to these changes. Accomplishing these goals requires the establishment of an accurate and precise chronology for each of the recovered cores. The sea-level history of the last ~30,000 years, including the lowest sea levels of the Last Glacial Maximum (LGM) and the record of the deglaciation, is a crucial piece of earth and ocean history. This record provides constraints on how fast sea level can rise, which is key for projecting future sea level rise. Furthermore, estimates of the current rate of sea level rise from satellite and tide gauge data require corrections for the continuing isostatic adjustment of the globe from the presence of former ice sheets. These corrections depend on an accurate record of sea level and ice sheets over the last 30.000 years, from several widely spaced sites. The GBR is an ideal location to refine models of glacial isostatic adjustment and identify sources of melt water. Estimating magnitudes and rates of future sea level change is an urgent scientific and societal problem and an accurate history of sea level will provide crucial information on past links between sea level and climate. Here we report U-Th coral ages for reefs that grew during the Last Glacial Maximum.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1130, Sebel Tully

Environmental drivers of coral reef development in the tropical eastern Pacific

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Local and global perturbations have been accelerating the decline of coral reef ecosystems in recent years. Sub-fossil records from many parts of the world suggest that these recent mass coral

mortalities documented are unprecedented on a millennial scale. Core records from reef frameworks off the Pacific coast of Panama, however, show a period of limited reef accretion from approximately 4,500-2,000 cal BP. Similar hiatuses in reef deposition are found in other parts of the Tropical Eastern Pacific (TEP). Climatological reconstructions of ENSO fluctuations suggest that historic ENSO variability caused the millennial-scale reef collapse. The presence of a depositional hiatus was independent of the intensity of upwelling; however, upwelling did have an influence on the timing and duration of the hiatus. Furthermore, upwelling significantly retarded long-term rates of reef accretion throughout the Holocene epoch. Both ENSO variability and upwelling influence the growth and development of modern coral reefs in the TEP, so it is not altogether surprising that these environmental fluctuations were also important in the history of reefs accretion. Understanding the effects of environmental changes on past coral reef development may, in turn, be the key to predicting the future of coral reef ecosystems in a changing climate.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1715, Sebel Tully

Dating anomalies in shallow reef core transect, Heron Reef, GBR

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Dated scleractinian coral skeletons from reef flats and shallow reef cores provide the basis for reef growth models and many Quaternary sea level and palaeoclimate reconstructions. However, geochemical data obtained from corals are subject to the quality of preservation of the skeletal aragonite, and meteoric diagenesis has long been known to disrupt original coral geochemistry. A shallow transect (5 cores, ~4-10 m depth, 5 m spacing) of cores on the western leeward reef margin of Heron Reef, southern Great Barrier Reef returned dates of ~4 - 7.5 ka using U-series dating by thermal ionisation mass spectrometry. The sampled leeward section reached current sea level before 5 ka and prograded seaward at ~16.7 m/ky. However, a zone of relatively intense early marine diagenesis immediately below the reef flat disrupts U-series ages causing apparent age increase upwards within the uppermost 1-1.5 m of reef rock. Against expectation there appears to be direct evidence of Th open-system behaviour that allowed preferential ^{230}Th mobilisation and enrichment in this environment. The high degree of diagenetic alteration may reflect proximity to the intertidal zone, with frequent wave and tidal pumping of water masses, temperature extremes, evaporation, CO_2 degassing and increased biological activity. For example, the zone below the reef flat is characterised by enhanced lithification by cryptic microbialites. The exact nature of the mechanism of ^{230}Th uptake is unknown, but if it is a widespread process, it has significant implications for many dated reef coral samples.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 0945, Sebel Tully

Unlocking reef growth and demise on the GBR since the Last Glacial Maximum

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Predicting how the Great Barrier Reef (GBR) will respond to future global climate changes and over what time frame is crucial. Fossil reefs record critical data on geomorphic and ecological consequences of both long-term and abrupt centennial-millennial scale environmental changes. The Integrated Ocean Drilling Program (IODP) Exp. 325 investigated a succession of submerged fossil reefs on the shelf edge of the GBR to establish the course of sea-level change, define sea-surface temperature variations but also analyse the impact of these environmental changes on reef growth since the Last Glacial Maximum (LGM). Thirty-four boreholes were cored from 17 sites along four transects at three locations (Hydrographers Passage, Noggin Pass and Ribbon Reef) in water depths between 42 to 167 m. These cores record responses of the GBR to past environmental stresses similar to current scenarios of future climate change (i.e. changing sea-levels, SST's, water quality). Initial lithologic, biologic and chronologic data document an active coral reef system that grew, drowned and backstepped up-slope as sea level rose since the LGM. We present an overview of the main Exp. 325 results, including a synthesis of the dating and reef response team's findings, in the context of the available site survey data (bathymetry, seismic, seabed imagery). Finally, we discuss the broader implications of these data for understanding how the geometry, composition and development of the GBR responded to repeated and major environmental disturbances since the LGM.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 0930, Sebel Tully

Sea-level changes since the Last Glacial Maximum: IODP new results from IODP Expedition 325

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Around 20 ka, during the last glacial maximum (LGM),sea level was at least 120 m lower and global climates were colder. Because environmental changes since the LGM comprise the largest magnitude changes in the Earth's recent history, the timing and courses of deglaciations are key components for understanding the global climate system and high resolution sea-level reconstructions are essential for paleoclimate studies. Cumulative evidence shows that last deglacial sea-level rises were not monotonic. When the Integrated Ocean Drilling Program (IODP) Expedition 310 reconstructed sea-level since 16,000 years ago from fossil coral reefs off Tahiti, the most prominent rapid-rise event (Melt Water Pulse 1a - MWP1a) occurred synchronously with a rapid warming event (B/A event) recorded in Greenland ice cores. Because the Tahiti cores did not reach fossil reefs that formed at the LGM, features of sea-level during and coming out of the LGM are known only from one Atlantic site (Barbados) and have not been constrained in detail by coral reef materials for any Indo-Pacific site. IODP Expedition 325 drilled 34 holes across 17 sites in the Great Barrier Reef, to recover LGM and post-LGM fossil reef materials. Preliminary dating clearly indicates that LGM materials were recovered. Continuing analytical activities include facies analyses and radiometric dating. We will summarize Exp. 325 preliminary dating results and their broader implications for understanding global sea level, based on more than 200 radiometric dates from corals and coralline algae, and present a glacio-hydro-isostatic model.

1B Reef response to sea-level & environmental changes
Tuesday 10 July, 1515, Sebel Tully

Theme 2. Palaeontology

2A Pantropical palaeontology of Cenozoic coral reefs

Towards a synthesis of Cenozoic pantropical paleontology

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The tropics hold the most diverse shallow marine ecosystems, and play a major role in controlling global climate. Study of past ecosystem response to environmental change provides critical information for understanding the long-term impacts of ongoing environmental change. Global changes are modulated by local environmental factors resulting in a regional pattern of biotic response. Each region can be thought of as treatments of a global-scale natural experiment. Was the response of ecosystems to rapid global changes similar? How connected are the regions biologically and what is the biogeographic pattern of change? Processes underpinning this response are migration, speciation and extinction. We expect that gradual and abrupt climatic, tectonic, and environmental alterations each leave their own signal. For most taxonomic groups, twenty-five years of Caribbean fieldwork has radically changed our understanding of the response of shallow marine ecosystems to regional environmental change. During the past five years, the volume of collections from SE Asia has increased by an order of magnitude. Much data exists in historical collections from the Mediterranean that currently are being pulled together. Moving forward, it is critical to build and integrate morphological and molecular collections from under-sampled groups and under-sampled regions. These new collections will force critical evaluation of previous taxonomy and will stimulate rapid development of a new global taxonomic framework. Recent advances in biodiversity informatics will permit integration of palaeoecological, geochronological and biozonational information and in turn will highlight the need for new age dates and an improved global correlation of biozones.

2A Pantropical palaeontology of Cenozoic coral reefs
Wednesday 11 July, 1545, Sebel Tully

Free-living corals of the pan-tropical Cenozoic

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Periods of accelerated origination and extinction have played a disproportionate role in shaping the structure and ecology of Cenozoic coral communities in the Caribbean region. This is most evident in the late Pliocene faunal turnover event in which approximately 80% of Mio-Pliocene corals became extinct and more than 60% of species now living in the region originated. Free-living solitary and flabello-meandroid (FSFM) corals are characteristic of this interval. Diverse communities of FSFM corals inhabited shallow near-shore to deeper oligophotic habitats of the Pliocene. Living unattached allows FSFM corals to inhabit sediment-rich environments where attached colonies are prone to smothering. Long tentacles make them suited to zooplankton capture and less dependent on symbiotic algae to meet nutritional requirements. FSFM corals were well suited to the low-angle depositional profiles, increased productivity, increased sedimentation, and warmer temperatures of this period. Origination rates of FSFM coral species between 8 and 4 Ma are roughly double other zooxanthellate corals. FSFM corals experienced abrupt extinction between 2 and 1 Ma, as environmental conditions changed and suitable habitat was eliminated. Are the diverse FSFM corals in the Mio-Pliocene of the Caribbean unique, or did similar faunas exist across the tropics? Available data sources are used to compare the Cenozoic history of FSFM corals in the Mediterranean and southeast Asia to that of the Caribbean.

2A Pantropical palaeontology of Cenozoic coral reefs
Wednesday 11 July, 1400, Sebel Tully

Long live the dead: per-capita preservation probabilities of lagoonal molluscs

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One of the most significant obstacles to comparing living communities and fossil assemblages is the ~ 5x variation in shell half-lives. Knowing taxon-specific preservation probabilities enables us to estimate the 'original', or biological, taxon abundance distribution from sedimentary death assemblages allowing us to compare subfossil assemblages to living biological communities. Here I present data on the durability of the molluscan fauna from Rib and Bramble Reefs (Great Barrier Reef, Australia). Using carbon-14 calibrated AAR ages, half-lives were determined for seven key taxa. These seven taxa are then used to investigate the correlation between shell half-life and morphological estimates of shell durability. These data demonstrate a strong correlation between measured half-lives and morphological estimates of

shell durability. This correlation is used to infer preservation probabilities for the entire molluscan fauna. The general utility of this method to estimate per-capita preservation rates for whole communities is explored in the context of modern and subfossil taxon abundance distributions.

2A Pantropical palaeontology of Cenozoic coral reefs
Wednesday 11 July, 1530, Sebel Tully

Georeferencing and geostatistics for coral reef modelling

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This study compares two methods of estimating diversity and morphological disparity of scleractinian coral communities in a well-preserved Oligo-Miocene reef of the Côte-Bleue, west of Marseille, France. A classical line-transect approach used a dozen 20-m long transects arranged over four intertidal bedding-plane outcrops of the reef. Subsequently, all identifiable corals within the four outcrops were mapped and georeferenced using a laser scanner and GIS. A series of maps based on the compilation of taxonomic, morphological and precise position data enabled the modelling of this paleofringing reef in 2D. The comparison of the two methods revealed advantages and drawbacks. The transect method was easy to execute, but missed some important variations in coral communities such as the spatial distribution of the colonies, the generic density index, the size of individuals, etc. Georeferencing and mapping all the colonies illustrated lateral changes in community composition in response to variations in the physico-chemical environment such as water depth, turbidity, burial rate, wave activity, etc. Mapping, however, requires continuous high-quality outcrop, and is very time-consuming. A compromise approach using multipoint geostatistics is proposed. It only requires precise mapping of a small part of the coral reef and random transects to stochastically generate 2D models of the entire reef. The goal of this approach is to reproduce the spatial variability of the coral reef while minimizing the time of mapping. Testing showed that, five 20m transects and $20m^2$ of mapping on each portion of outcrop was sufficient to map paleoecological variations along the fossil reef.

2A Pantropical palaeontology of Cenozoic coral reefs
Wednesday 11 July, 1515, Sebel Tully

Filling the 'Paleogene Gap': coral diversity from Oligocene Borneo

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A diverse fossil assemblage of stony corals has been collected from the Kinabatangan region of Sabah in Malaysian Borneo. The fossil deposits studied have been accurately dated using a combination of nannofossils, larger benthic foraminifera and strontium isotopes, placing them well within the Oligocene epoch (between 30 and 23 m.y.a.), where previously they were thought to be of early Miocene age (between 23 and 16 m.y.a.). The corals have been taxonomically identified to genus-level and placed into likely species groups within each genus. There are thought to be approximately 100 species present in this collection from within (a conservative estimate of) 52 genera. This fauna has been compared to contemporary coral faunas from around the world, as well as to coral faunas collected within the Indo-West Pacific (IWP) region dating from both Miocene and Recent times. The collection presented here is one of the most taxonomically diverse assemblages of corals from the Oligocene epoch, showing that high reef-coral diversity was around in the present-day marine biodiversity hotspot area earlier than has been previously known, and also that some species have had a much longer residence time in the IWP than has been previously thought.

2A Pantropical palaeontology of Cenozoic coral reefs
Wednesday 11 July, 1500, Sebel Tully

Climate as a driver for past Indo-Pacific coral reef development

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Environment and climate shifts are not unique to the present day and are always accompanied by taxonomic and distributional changes in marine ecosystems. One of the most diverse and complex ecosystems is coral reefs. While progress is being made to understand the response of present coral reefs to environmental change, our knowledge about past coral communities and natural drivers of both speciation and extinction is limited, especially in the Indo-Pacific. The Indo-Pacific biodiversity hotspot dates from the Early Miocene (23 MA), presently holds the most diverse coral communities in the world, and supports a large number of other marine organisms. We studied fossil coral assemblages aged between 28 and 19 MA from Sarawak, Borneo where previous information on ancient reef diversity is lacking. Analysis of past marine assemblages from four localities in Sarawak reveals a dramatic shift in marine communities from

foraminifera dominated reefs throughout the Eocene and Oligocene to coral dominated communities in the Early Miocene. This shift was associated with a change to warmer and less seasonal climates, and marks the origin of the Indo-Pacific biodiversity hotspot. Hence, climate change is a major driver of reef development in the recent geological past.

2A Pantropical palaeontology of Cenozoic coral reefs
Wednesday 11 July, 1445, Sebel Tully

Niche conservatism is stronger in ancestors than descendants

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The expansion of Caribbean reefs after closure of the Isthmus of Panama dramatically increased the range of habitat types available to cupuladriid bryozoans in the coastal seas of the southwestern Caribbean. Evidence from the occurrences and abundances of fossil cupuladriids across a suite of habitat gradients demonstrates that young cupuladriid species swiftly expanded into these new habitats, whereas their surviving ancestors took a further two million years to achieve a similar expansion. The ability of a species to take advantage of new habitat may therefore vary through the life trajectory of a species.

2A Pantropical palaeontology of Cenozoic coral reefs
Wednesday 11 July, 1415, Sebel Tully

On the origins of the coral diversity in Southeast Asia

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Evidence from palaeontological and molecular studies suggests that the Miocene was an important period for diversification in the SE Asian centre of maximum marine biodiversity. As part of the Throughflow ITN, this research aims to know how diverse corals were during the Miocene and which environmental factors controlled their diversification on both, temporal and spatial scales. Our new collections include tens of thousands of specimens from delta-front patch reefs of Miocene age (Burdigalian to Messinian, 20-5 Ma) located in East Kalimantan (Indonesia). Preliminary results suggest that species diversity was comparable to modern coral settings living under similar environmental conditions for distinct platy and branching coral assemblages. A total of 51 morphospecies (36 genera) have been identified so far, from which only three genera are now extinct, *Dictyaraea*, *Anisocoenia*, and *Fungophyllia*. Coral morphologies seem to respond to the gradient of siliciclastic sediments and nutrients input created by the progradation of the Mahakam Delta since the Early Miocene. This large river plays an important role in structuring regional ecosystems. Platy-coral assemblages were common in the vicinity of the delta, characterized by a higher turbid-water regime, and mainly from the Early to Middle Miocene. On the other hand, communities of branching corals mixed with scattered massive corals were more frequent during the Late Miocene in settings located towards the north, characterized by less deltaic influence. Future research, including sedimentological and geochemical analysis, will focus on disentangling the influence of major global environmental changes and the regional progradation of the Mahakam Delta on species turnover.

2A Pantropical palaeontology of Cenozoic coral reefs
Wednesday 11 July, 1430, Sebel Tully

High-resolution palaeoenvironmental records from Miocene patch reefs from SE-Kalimantan, Indonesia

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The development of the extraordinary coral reef diversity in SE-Asia is a response to long-term environmental changes resulting from the closure of the Indonesian Throughflow (ITF) during the Oligocene-Miocene transition. To disentangle the complex relationship between the tectonic history of the ITF and associated environmental changes, paleoclimatic reconstructions are required. Here we present seasonally-resolved palaeoenvironmental records obtained from Miocene corals and molluscs. Corals and molluscs are increasingly used as archives for paleoclimatic reconstructions, as they incorporate and store the elemental and isotopic composition of their ambient marine milieu. However, certain restrictions apply, as diagenetic processes such as recrystallization of aragonite to calcite or secondary aragonite precipitation lead to an overprint of the original geochemistry, resulting in unreliable palaeoenvironmental reconstructions. Thus, to obtain reliable paleoclimatic information, primary coral/mollusc aragonite is required, which however, is rarely preserved in 'deep time' Miocene or older strata. Here, we present initial aragonitic results of well-preserved Miocene corals and molluscs from East Kalimantan, Indonesia. Besides long-term records from corals, co-existing giant clams (*Tridacna* sp.) are of special interest, as they preserve a decadal record of interannual environmental variability. Trace element/Ca ratios from laser-ablation mass spectrometry (LA-ICPMS) and micromilled $\delta^{18}O$ data are used to infer seasonally-resolved changes in climatic (e.g. SST) and environmental (e.g. SSS) conditions. Obtained numerical ages are based on strontium isotope stratigraphy.

2A Pantropical palaeontology of Cenozoic coral reefs
P006

2B. Coral reefs: is the past the key to the future?

Transient metazoan reefs in the aftermath of the end-Permian mass extinction

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Recovery from the devastating Permian-Triassic mass extinction about 252 myr ago is usually assumed to span ~5 myr, the entire Early Triassic epoch. The post-crisis interval was characterized by large-scale fluctuations of the global carbon cycle and harsh marine conditions, including a combination of ocean acidification, euxinia, and fluctuating productivity. During this interval, metazoan-dominated reefs are thought to have been replaced by various microbial deposits that are considered the hallmark of the Early Triassic. Contrasting with this consensual recovery scenario of a delayed recovery of complex benthic communities, we document metazoan-rich bioaccumulations and reefs from the western USA, formed only 1.5 myr after the extinction. These bioconstructions are comprised of various sponges and serpulids associated with microbialites and diverse eukaryotic organisms. We conclude that the predominance of microbial reefs following the mass extinction is restricted to short intervals during the earliest Triassic. We suggest that metazoan reef building continued throughout the Early Triassic wherever permitted by environmental conditions. However, the absence of corals, or their failure to calcify, remains remarkable for the Early Triassic and contrasts with their flourishing in later Triassic times. The absence could be due to the inability of these stenotypic reef builders to cope with intermittent deleterious conditions, especially potential acidification. While present-day reefs are most likely headed towards a severe extinction, these findings remind us that biotic recovery after an extinction event is a rapid phenomenon at the geological time scale, but a very long evolutionary process at the biological (human) time scale.

2B Coral reefs: is the past the key to the future?
P007

Can flooding rainfall events be revealed in oceanic coral cores?

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Fundamental questions remain about why the Coral Sea reefs and cays have developed where they are and what their importance is on a larger scale. Under various seasonal influences including the strength of climate anomalies, such as the El-Niño Southern Oscillation, the bifurcation of oceanic currents migrates within the vicinity of the Lihou and Coringa-Herald reefs, greatly influencing the large-scale circulation of the Coral Sea. Additionally, the oceanic setting of the Coral Sea reefs and cays provide a fantastic habitat to investigate chemical and isotopic interpretative records such as temperature, salinity and nutrients, without the blurring effect of terrestrial influence. Through the use of now-standard palaeoclimatological techniques on samples from the Coral Sea reefs, it is hoped that it will be possible to evaluate the practicability of using deep sea reefs as interpreters of past climate conditions in other regions. Specifically, cores of large *Porites* sp. can be geochemically analysed for freshwater anomalies, thus acting as proxy rainfall records and potentially informing on climate records onshore. The Coral Sea represents a significant source of the onshore tropical rains in the form of low pressure systems that bring flooding rains to the east coast of Australia. These systems often pass southwards along the coastline, possibly penetrating inland, along predetermined pathways where they introduce flooding rains to the inland. Long term records of these low pressure regions within coral cores from Coral Sea reefs and cays could provide more robust statistical characterisations of the flooding rain events witnessed in the past few years.

2B Coral reefs: is the past the key to the future?
P008

Reconstructing a pristine non-coral reef community in the southwestern Caribbean

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Caribbean reef communities have suffered a battery of anthropogenic disturbances and many strategies have been proposed to improve the situation. However, their goals are inconsistent since they have little information on what a healthy Caribbean coral reef 'should' look like. Only fossils can describe a truly pristine reef community, i.e. one without human influence. The paleontological approach has been applied to corals up to several thousand years old, but a reef community contains far more than just corals. To address this

deficiency, we explored the differences in the molluscan communities between a 120ka *Acropora cervicornis* dominant reef and lagoon, and a modern reef and lagoon in the Bocas del Toro archipelago in Panama using bulk samples. Although most species were represented in both pristine and modern benthic communities, we found strong differences in the relative abundance of taxa across time with a considerably greater percentage of herbivorous and carnivorous taxa in pristine communities and an increase in planktotrophic organisms in the modern community. Even more striking was the decrease in bivalve and gastropod size from pristine to modern reef across a swathe of ecological groups. Long-term declines in Caribbean reef health are not restricted to corals, but instead appear to have changed entire benthic communities.

2B Coral reefs: is the past the key to the future?
Wednesday 11 July, 1700, Sebel Tully

The Pleistocene Key Largo reef: a key to the future?

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Will barrier reefs in a warm future turn into ramps with slow-growing corals? The modern Florida Reef Tract has a barrier reef-type morphology whereas the underlying last interglacial Key Largo Limestone was deposited on a ramp. Skeletal extension-rates and their variability are significantly lower in Pleistocene massive reef-building corals (*Montastraea annularis* group) from the Key Largo Lst. as compared to *Montastraea* in the modern Florida Reef Tract. We analyzed 1,429 annual increments in 18 cores of *Montastraea* colonies in the Pleistocene Key Largo Lst. The average extension-rate is 5.2 mm/yr, which is about half the value known for modern *Montastraea* in shallow water reef environments. With an average standard deviation (SD) of 1.01, the variability of extension-rates is at the lower range limit of modern *Montastraea* in south Florida (SD = 1-3.6). Due to the higher sea level, the Pleistocene Key Largo patch reef trend was located on a large carbonate platform. Unlike today, the island chain of the Florida Keys, which function as a shelter for the Florida Reef Tract from inimical bank water, was not in existence; a bank barrier margin as seen today did not exist. Corals probably grew under higher-than-present sea surface temperatures, which resulted in comparably low skeletal extension-rates. Still, the detection of 3-7 year, decadal, and multi-decadal cyclicities in extension-rate time series suggests that the major modes of modern tropical climate variability such as the El Niño-Southern Oscillation (ENSO) and possibly the Atlantic Multidecadal Oscillation (AMO) were in effect during the last interglacial.

2B Coral reefs: is the past the key to the future?
Wednesday 11 July, 1645, Sebel Tully

Historical context for the decline of Caribbean coral reefs

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We have assembled a literature-derived database of reef coral community structure throughout the Caribbean region during four distinct intervals of time: fossil reefs include those from Last Interglacial (~130-119 kybp) and Holocene (~10-3 kybp) time. Modern reefs include those surveyed prior to 1983 and those surveyed after 1983. The data are drawn from 287 individual literature sources published through 2010 and represent 2641 localities. Ten reef environments have been identified, ranging from exposed reef flats to >30m depth. Coral species were ranked according to their abundance at each locality in order to compare patterns of change in coral community structure within distinct reef environments during intervals free of anthropogenic stress (the fossil reefs), and those that have witnessed increasing anthropogenic influence (the modern reefs). A total of 91 coral species occur in the data set. Five reef environments account for 75% of the localities examined. To date we have investigated the percent of localities dominated (highest rank order abundance) by common Caribbean corals in each of these environments. Highly variable patterns of coral dominance over time are observed. For example, in reef crest environments, a long-term decline in the percent of localities dominated by the acroporids and *Montastraea* is observed and is accelerated on modern reefs for *Acropora palmata*. Long-term decline in *Acropora cervicornis* in mid-slope (5-15m depth) environments also is observed, but decelerated between 1983 and 2010. Our database is a unique resource that may provide historical context to the current widespread reef decline in the Caribbean region.

2B Coral reefs: is the past the key to the future?
Wednesday 11 July, 1730, Sebel Tully

Coral reefs environments after the Triassic-Jurassic boundary crisis

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The Triassic-Jurassic boundary (at ~200 million years ago), is considered as one of the big five mass extinction events of the Phanerozoic but the causes remain controversial. Many authors report that the end of Triassic was marked by an important

increase in pCO_2 which induced a global warming. One author has suggested that this important increase caused a $CaCO_3$ undersaturation of the oceans which consequently induced a biocalcification crisis. Thus, the reef communities, and especially the corals suffered high extinction rates. Before the recovery of reef building during the Dogger, the Lower Jurassic is characterized by a 'reef gap'. Thereby early Liassic outcrops, showing genuine frameworks of colonial corals, are very scarce and essentially concentrated in the Western Europe (western Tethys). In order to better understand the palaeoenvironmental conditions that prevailed in the western Tethys just after this crisis, different coral reefs were studied in the western part of Europe. This present work is the first description of Upper Sinemurian reefs situated on the Cevennes-margin (southern France). The sedimentological setting reveals that those metric to decametric reefs grew in quite high hydrodynamic conditions, periodically influenced by storms. Their compared morphology and nature is variable but globally, their coral density and diversity are fairly low. The corals are dominantly massive to ramose cerioid (*Chondrocoenia*, *Heterastrea*) occasionally dendroid and phaceloid, exceptionally plocoid. Additionally, oysters are often abundant and microbialites inconspicuously occur in those bioconstructions. To obtain palaeotemperatures, geochemical analyses on oyster shells are in progress.

2B Coral reefs: is the past the key to the future?
P009

Climatic control of Oxfordian reef coral distribution (Late Jurassic)

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The Jurassic was thought to have been a period characterized by a predominantly warm and equable climate. During the Oxfordian- a time span of 6 million years in the Late Jurassic- the distribution of tropical coral reefs was limited to about 35°N and near to 25°S. However, in Middle Oxfordian, coral reefs were abundant only at higher latitudes and almost entirely missing near the equator. During that time the area of maximum reef development had shifted poleward to a belt lying between 20°N and 35°N leaving hardly any coral formations at the lower inner tropical latitudes. After their demise towards the end of Middle Oxfordian time, low-latitude reefs recovered during the Late Oxfordian accompanied by a southward migration of reef corals in the northern hemisphere. The bibliographic compilation and fieldwork- in Western Europe and northwestern Africa- combined with stable isotope analyses suggested that the faunal migration and variations of coral diversity can be correlated with a significant rise in seawater temperature during the Middle Oxfordian and so by the ongoing global warming and cooling processes. Low to medium diversities observed in coral associations in the coral reefs pioneering and terminal reef phases correlate well with average seawater paleotemperatures below 20.3°C. The reef climax coincides with optimum environmental conditions, reflected by a high coral diversity and an average seawater temperature between 22°C and 30°C. The results of this study show that water temperatures set the physiological limits for the distribution of corals and coral reefs in Oxfordian time.

2B Coral reefs: is the past the key to the future?
Wednesday 11 July, 1745, Sebel Tully

Adaptation potential of 'Reef Ecosystem Atavisms' for the Anthropocene

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The evolution of reefs since the Proterozoic is characterised by a long-term increase in reef system modules (microbial, soft and siliceous sponges, gregarious hard-shelled metazoans, photosymbionts, and coralline algae). Scleractinian coral reef adaptations since the Late Triassic are characterised by perfecting the photosymbiontic system. Jurassic coral reef ecology still reflects a wider set of growth environments relative to today, with different reef types thriving from brackish to mesotrophic, sediment-laden, to oligotrophic environments. Tipping point-shifts of modern reefs from healthy to soft coral/algal-dominated to heterotrophic/microbial appear to reflect in-place 'atavistic' switches to an evolutionary less complex state with a reduced number of modules. The Caribbean Almirante Bay, Panama, may be a present-day equivalent of adaptation of reefs to increased terrigenous runoff and nutrient levels: isotope and molecular studies indicate an increase in filtering relative to photosymbiontic activity, and changes in dominant coral species, overall organismic composition and structure, resemble Jurassic coral reef thickets of mixotrophic environments characterised by terrigenous runoff. Whether or not these atavistic coral reef types might firmly establish themselves and might have potential to substitute declining oligotrophic reefs will be strongly governed by the rate and scale of global and local environmental changes. However, owing to their reduced diversity and flat spatial structure these reefs will not be able to substitute all ecosystem services as provided by high-complexity

coral reefs. Nevertheless, reef conservation under an anthropocenic view should not only manage and protect oligotrophic 'healthy' reef sites but also those under stress, in order to allow for 'atavistic' adaptation.

2B Coral reefs: is the past the key to the future?
Wednesday 11 July, 1715, Sebel Tully

Partial mortality and re-sheeting in fossil corals: a disease proxy

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Coral skeletons preserve growth histories over tens to hundreds of years, and therefore growth irregularities in the cross sections of colonies can provide a semi-quantitative estimate of disease and other damage over significant periods of ecological time. Here I examine the incidence of growth interruptions and regrowth in cross sections of large Pleistocene coral colonies of Curacao. Hundreds of large, mostly in-place, colonies of *Acropora palmata* from three time intervals (216ky, 122ky, 120ky) and three environments (windward reef crest and flat, and leeward reef crest) were examined. All samples had a low incidence (0-3%) of growth interruption and regrowth as marked by partial horizons of bioerosion and encrustation within the coral colony. No examples of large scale resheeting, as is occurring today on skeletons remaining from the white band die-off of the 1980s, were observed. Large coral domes (>1m in cross section) were similarly undistorted over their life spans suggesting that coral disease and partial mortality were generally rare in the Pleistocene reefs of Curacao. These results provide a pre-human baseline that stands in strong contrast to recent Caribbean reefs that have experienced the large scale die-off of *Acropora*, and the increasing prevalence of coral disease and partial mortality.

2B Coral reefs: is the past the key to the future?
Wednesday 11 July, 1750, Sebel Tully

Community assembly and dynamics in marine lakes of the Western Pacific

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Marine lakes are isolated bodies of sea water, and are unique ecosystems ideal for evolutionary and ecological studies. Paleo-ecological studies on community assembly and the processes that affect species distribution and abundance should give insight into the consequences of future climate change, including how populations will persist or fluctuate. My study is on foraminifera in marine lakes, to identify the processes that play a major role in affecting species' changing contributions to biodiversity. Paleontological methods to enumerate species dynamics through Holocene sediment cores will provide data that relate community dynamics relative to habitat (marine lake) size, distance from the ocean, population size, and environmental variables. This will be a high-resolution and long-term biological dataset on climate change in the western Pacific.

2B Coral reefs: is the past the key to the future?
P010

Reef accretion on the outer shelf of Southwest Puerto Rico

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Previous coring studies in southwest Puerto Rico documented the enigmatic give up of shelf edge reefs at ~6.5-6.8 ka, with modern coral cover at these sites representing just a thin veneer over a relict substrate. Just landward of the shelf edge lie a series of submerged, oval-shaped, low-relief, hummock reefs that form the dominant habitat of the outer shelf of southwest Puerto Rico. Water depth over the tops of the hummock reefs as well as their morphology suggested that they succumbed to the same regional give-up event that affected shelf-edge reefs. However, recent shallow coring of these reefs is suggesting that they represent areas of very active and recent reef accretion, with 1 to 2 m of accretion occurring in the last ~700 years. While deeper cores may eventually reveal a relict substrate, this level of recent accretion was not evident in shelf edge cores from earlier studies. The outer-shelf hummock reefs off southwest Puerto Rico are an areally extensive habitat that is largely uninvestigated and may represent an important area of high coral cover and active reef accretion. Coral growth is likely favored here as the reefs are removed from nearshore stressors and have plenty of accommodation space. Understanding the spatial and temporal relationships of these reefs with the well-studied shelf-edge and emergent middle-shelf reefs improves our understanding of larger scale controls on reef growth. Additionally, understanding the environmental conditions allowing for high coral cover and recent accretion will help in accurately identifying stressors to adjacent reef systems.

2B Coral reefs: is the past the key to the future?
Wednesday 11 July, 1755, Sebel Tully

Ocean acidification and the 'naked coral' hypothesis

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Ocean acidification is one of the pressing issues in analysis of present-day coral decline and the future

of reefs. Among some mass extinctions affecting ancient reef ecosystems, ocean acidification was implicated and the past is a vital link to understanding the present. The largest mass extinction of the end-Permian, 253 mya, has been associated with massive and sudden changes in the global chemistry of the seas and changes in ocean pH or ocean acidification. The end-Triassic extinction and reef collapse 200 mya, has strong evidence for ocean acidification. Affected were hypercalcifying taxa, which were unbuffered against the effects of pH change. There also is a gap in reefs following the Permian extinction. While evidence exists for an early start of reef recovery, full ecosystem recovery took place in steps and was not completed until Middle Triassic time. In the evolution of reef ecosystems, the appearance of scleractinian corals in the Middle Triassic was important because it shaped the subsequent ecosystem of the Mesozoic-Cenozoic. It is problematic because of the lack of any scleractinian ancestors in earlier Triassic intervals. However unusual Paleozoic scleractiniamorphs are known. Ideas presented on the ephemeral nature of calcification in scleractinian corals are relevant and shaped the 'naked coral hypothesis'. They suggested that coral ancestors survived the extinction in 'naked' form and this explains important aspects of the survival and recovery. It also has relevance to the idea of Lazarus taxa or ancient organisms that appear to leap-frog large intervals of geologic time, apparently undetected.

2B Coral reefs: is the past the key to the future?
Wednesday 11 July, 1630, Sebel Tully

Theme 3. Evolution, biogeography & taxonomy

3A Evolution, biogeography & taxonomy

Past and present patterns of gene flow in *Caesio cuning*

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The redbelly yellowtail fusilier, *Caesio cuning*, has a tropical Indo-West Pacific range that straddles the Coral Triangle, a region of dynamic geological history and the highest marine biodiversity on the planet. *Caesio cuning* is a reef-associated artisanal fishery, making it an ideal species for assessing regional patterns of gene flow for evidence of speciation mechanisms as well as for regional management purposes. We evaluated the genetic population structure of *Caesio cuning* using a 382bp segment of the mitochondrial control region amplified from over 620 fish sampled from 33 localities across the Philippines and Indonesia. Phylogeographic analysis showed that individuals sampled from sites in Western Sumatra belong to a distinct lineage, resulting in pronounced regional structure between Western Sumatra and the rest of the Coral Triangle (ΦCT =0.4596, $p<0.0031$). The species' range and measures of genetic diversity at these Indian Ocean localities point toward low effective population size west of Sumatra and indicate that historic changes in sea level and ocean currents during periods of Pleistocene glaciation may have led to divergence between *Caesio cuning* populations west and east of the Sunda shelf. Analysis of sites in the Pacific lineage indicates some isolation by distance ($r = 0.2071$, $p<0.0162$). Evidence for limited migration as well as the distribution of haplotypes across our sampling range suggests that current oceanographic patterns could be contributing to observed patterns of structure. Continuing research is focusing on smaller, management-scale analysis of connectivity in *Caesio cuning* via the development of SNP and microsatellite makers from next-generation sequencing methods.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1645, Sebel Tully

Regional differences in species diversity and chemotypes: soft coral *Sarcophyton*

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Soft corals (Subclass: Octocorallia) are a group of anthozoans that are among the most common members of coral reef communities in tropical waters. Research on the soft coral genus *Sarcophyton* extends over a wide range of fields, including marine natural products and the isolation of a number of cembranoid diterpenes. However, relationships between species diversity of *Sarcophyton* and cembranoid diterpene production is not clear. In a previous study, the biodiversity of *Sarcophyton* and its major metabolites showed close relationships utilizing chemotype identification and phylogenetic examination of *Sarcophyton* (utilizing mitochondrial protein-coding genes mutS homolog: msh1) from Okinawa Island in Japan. In this study, in order to examine the influence of specimen region on the relations between metabolites and *Sarcophyton*, samples from southern Japan and Indonesia were investigated. Additionally, to further assess diversity of *Sarcophyton*, each sample was analyzed by using DNA markers (msh1, extended barcode of msh1, COI with a short adjacent intergenic region: COI + igr1 + msh1). Furthermore, to reveal diversity of the cembrane contained in *Sarcophyton*, the cyclase gene encoded in the *Sarcophyton* genome was searched for by comparison among cyclase proteins and diterpene genes already identified.

3A Evolution, biogeography & taxonomy
Friday 13 July, 1000, Sebel Tully

Phylogenetic position of *Symbiodinium* in *Zoanthus gigantus*

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Dinoflagellates in the genus *Symbiodinium* form obligate symbiotic relationships with a variety of coral reef invertebrates. These symbionts are variable in morphological and physiological properties, especially their differential tolerances to bleaching. To understand the diversity that exists in subtropical and tropical waters it is important to look at the symbionts in a variety of cnidarian hosts. To date no study has focused on the genetic diversity of *Symbiodinium* spp. in *Zoanthus gigantus* utilizing a hypervariable region in domain V of the large subunit of the chloroplast ribosomal array (cp23S-HVR) and the internal transcribed spacer 2 region of the nuclear ribosomal array (ITS2). *Zoanthus gigantus* is a reef-dwelling zoanthid (Cnidaria: Anthozoa: Hexocorallia: Zoantharia) found from intertidal to 30 meters deep. This study examined the phylogenetic position of the *Symbiodinium* spp. in *Z. gigantus* from mainland Japan to Australia,

also including specimens from Taiwan, Okinawa Island, Ishigaki Island, and Singapore from intertidal to 15 meters. Examining the diversity and identity of subclades or species of clade C *Symbiodinium* found in *Z. gigantus* will help establish an understanding of how temporal and spatial aspects play a role in the distribution of the 'host generalist' clade C of *Symbiodinium*.

3A Evolution, biogeography & taxonomy
P011

Does polyp size constrain the morphological diversity of coral colonies?

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Adaptation is frequently invoked in the literature as the proximate cause of the huge morphological diversity of corals. Conversely, little attention is paid to phylogenetic, developmental or architectural constraints, ignoring the possibility that some morphological patterns may not result from adaptation, but exist because alternative morphologies have not or cannot evolve. I hypothesize that shape diversity in colonial corals is constrained by polyp size. Architectural features of a colony cannot be smaller than the polyps themselves because the polyps are the building blocks of the colony. Hence, species with small polyps can build colonies with complex or simple shapes, but species with large polyps are constrained to simpler growth forms. The main prediction of this hypothesis is that species with complex colonial shapes and large polyp sizes should not exist. A morphospace was built using data acquired from dry museum specimens. Information theory was used to quantify colonial complexity and calyx diameter was used as a proxy for polyp size. A null distribution pattern was generated using Brownian motion to simulate the evolution of both traits onto phylogenetic trees sampled from a posterior distribution obtained via Bayesian analysis of molecular data. The observed distribution of individuals within the morphospace departs significantly from the expectation under the null and matches the prediction of the proposed hypothesis. These results imply that constructional morphology offers a much more attractive explanation for the evolution of the colonial scleractinian Baupläne than the functional hypotheses advanced so far.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1730, Sebel Tully

Coral reefs as drivers of cladogenesis

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Estimating the temporal origins of biodiversity may hold the key to understanding the historical forces that have shaped biodiversity hotspots. We quantified diversification rates through time for four reef fish families (Labridae, Chaetodontidae, Pomacentridae, Apogonidae) using Bayesian inference. Lineage through time plots revealed a possible late Eocene/early Oligocene extinction event coinciding with the collapse of the Tethyan/Arabian hotspot, while diversification analysis revealed elevated cladogenesis in the Oligocene/Miocene. Lineages with more coral reef associated taxa display significantly higher net diversification rates than expected: the development of a complex mosaic of reef habitats in the Indo-Australian Archipelago (IAA) appears to have been a significant driver of cladogenesis. It was also a refuge from high extinction, as reef taxa are able to sustain significant diversification at high extinction rates. The IAA thus appears to support both cladogenesis and survival in reef associated lineages, laying the foundation for the Recent IAA marine biodiversity hotspot.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 0930, Sebel Tully

Phylogeography of the reef algae *Sargassum* spp. in Southeast Asia

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Southeast Asia is biologically one of the most diverse in the world. Lowering of the sea level during the Pleistocene (2.4 Ma - 10,000 year ago) resulted in the formation of land-bridges. These separated the major ocean basins and led to genetic isolation of many populations. Oceanic currents are also found to be dispersal barriers for many marine organisms and contribute to genetic isolation. On the other hand, these currents could also contribute to mixing of populations. Preliminary results from the phylogeographic studies of two *Sargassum* spp., *S. polycystum* and *S. cristaefolium* using Internal Transcribed Spacer 2 (ITS2), RuBisCo spacer and TrnW_I spacer as molecular markers, show genetic difference between populations from the western Malaysian Peninsula, southern Indonesia and the Philippines. This may suggest that these populations were isolated during the Last Glacial Maxima (LGM). However, some mixing of haplotypes was also recorded, suggesting post-glacial recolonization from adjacent refugia, which may subsequently have been affected by recent current flow. Among the Philippine populations, those from Davao in the south show genetic difference from the rest of the northern sites. Davao is located in the Sulu-Sulawesi Basin and this basin was isolated from the South China Sea Basin during the LGM. Thus, the Davao population may represent a relic population. The Davao population is also genetically closest to the Bali population in Indonesia, and shared haplotypes were also found among Davao and Malaysian

populations. This may be explained by the presence of limited current flow from the Sulawesi Basin to the Java Sea through the Makassar Strait.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1530, Sebel Tully

Evolution of column morphology in the sea anemone family Aliciidae

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Using a molecular phylogeny, I investigated evolution of column morphology in the sea anemone family Aliciidae. There are four valid genera in this family, *Alicia*, *Lebrunia*, *Triactis*, and *Phyllodiscus*, and most species are found in shallow reefal environments. Individuals in this family form symbiotic relationships with unicellular zooxanthellae and harbor these photosymbionts in branched structures on the body column. There are two types of elaborate column morphology in Aliciidae: pseudotentacles and vesicles. Pseudotentacles are branched outpocketings of the column and are unique to Aliciidae, although found in only three of the four genera. Vesicles are bumps or spherical outgrowths with ectoderm dense with nematocysts and found in all aliciids. Pseudotentacles are thought to increase surface area and access to light for photosymbionts, whilst vesicles are thought to aid in defence due to their dense nematocysts. Pseudotentacles differ among the three genera; *Phyllodiscus* individuals possess elaborate and highly branched pseudotentacles compared to *Triactis* or *Lebrunia* individuals, which possess moderately branched pseudotentacles. Vesicle morphology differs among Aliciidae; *Alicia* individuals possess compound and multiple types of vesicles, *Lebrunia* individuals possess multiple types of vesicles, whilst *Triactis* and *Phyllodiscus* individuals possess a single type of vesicle. I will use the topology of the phylogeny to investigate the evolution of these complex characters. For example, I will investigate whether possession of multiple highly branched pseudotentacles is a derived state in comparison to moderately branched or lack of pseudotentacles. The integration of phylogenetic and morphological data will shed light on the evolution and taxonomy of complex morphology.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1115, Sebel Tully

Demographic history of reef fish fauna in a biodiversity hotspot

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Establishing conservation strategies for biodiversity requires as a priority the identification of sites of interest regarding the distribution of fauna and flora. The `Hotspots' concept refers to locations with significantly higher biodiversity but also with high rates of endemism. However, our understanding of the biodiversity of these hotspots is still limited. French Polynesia presents a location of particular interest. It is the only biogeographic region of the Indo-Pacific with three areas of high endemism: the Marquesas, the Austral and the Gambier archipelagos. All of them present rates of endemism for reef fishes among the highest of Indo-Pacific. We investigated the demographic events that endemic reef fish species experienced in the Gambier and the Marquesas archipelagos and compared them to their cosmopolite close relatives (same genus) with similar life traits. Three mitochondrial markers and two nuclear markers allowed us to assess historical demographic events at different temporal scales due to differences in their effective population sizes and substitution rates. We used 8 couples' endemic species - sister species' in order to characterise fish fauna of these remote places. According to mitochondrial markers, all species seem to share similar history with a recent bottleneck followed by a population expansion. However, nuclear markers suggest that an older bottleneck occurred only in endemic species. It may be the consequence of a smaller environmental disturbance and reveals that endemic species can be subject to population size reductions events more often than cosmopolite species and therefore be more vulnerable.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1030, Sebel Tully

Phylogeny of the two ancestral hexacoral orders: Zoantharia and Actiniaria

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Subclass Hexacorallia is comprised of six orders, which collectively are among the most common marine benthos. In particular, their diversity is considered to be high in coral reef areas in the subtropics to tropics. Each order in Hexacorallia has been considered to be monophyletic, however, the relationships between the different orders are still uncertain due to a deficiency of taxonomic information caused by a lack of the studies at the species and genus level, as well as due to a lack of researchers. Zoanthids (=order Zoantharia) are one 'neglected' group of Hexacorallia. Zoanthids are distributed from the intertidal to the deep sea. In recent years, several previously unknown taxa have been described from the Pacific Ocean, including the family Microzoanthidae, shown to be highly genetically divergent from all other hexacorallians with a phylogenetic position close to order Actiniaria, but still within Zoantharia based on morphological characters. Additional other phylogenetically, highly divergent, undescribed

zoanthids have been found from shallow coral reef areas, as have undescribed or uninvestigated Actiniaria (sea anemones). These findings have led us to re-examine the phylogenetic relations between these two orders. These two orders have been previously shown to be the most ancestral groups in subclass Hexacorallia. To re-examine the phylogenetic relationships between these two groups, we report on new phylogenetic analyses utilizing multiple mitochondrial and ribosomal DNA markers. The results suggested that while each order is a likely monophyletic, the genetic distance between the orders is much closer than previously thought.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1700, Sebel Tully

Coastal boundaries and ecological traits; biogeography of Australian cryptobenthic fishes

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Understanding the mechanisms that limit coastal biogeographic ranges of marine species is important for quantifying biodiversity and decisions about conservation. Studies to date have focused on associations between larger, conspicuous fishes and physical features (topological and oceanographic) of the coastline and with tropical species expatriating from their 'typical' biogeographic range. However, the smaller, more cryptic reef fishes (CRF) have been largely understudied. CRFs are highly diverse, habitat-specific and, as such, may provide a valuable insight into overall species biodiversity and ecosystem functioning. In this study, we look at associations between range endpoints of CRFs along the entire Australian coastline and oceanographic and topographic boundaries that are likely to limit species' distributions. A database of over 1000 Australian reef fish species allows us to contrast a number of macroecological traits, including habitat preference, depth range, reproductive mode, and different classifications of cryptic habit. Concentrations of endpoints highlight several important boundaries on the Australian coastline and endpoint type (i.e., start or end of species range) gives insight into how these boundaries are operating. Preliminary results suggest that CRF ranges are more sensitive to topological boundaries such as headlands. These results greatly enhance our knowledge on CRF biogeography and the oceanographic and topographic mechanisms that act to constrain distributions. This enhanced understanding of biogeographic barriers will help us understand which species are better able to relocate under different environmental and climate change scenarios and which might require assistance in order to conserve biodiversity.

3A Evolution, biogeography & taxonomy
Friday 13 July, 1015, Sebel Tully

Dissection of a 'model' organism: exploring the molecular and morphological diversity of *Aiptasia* spp.

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Sea anemones belonging to the genus *Aiptasia* have been used as a model organism in an increasing number of studies detailing mutualism of dinoflagellate-cnidarian symbiosis, bleaching mechanisms, and invertebrate reproduction. Despite its use in several disciplines of biology, many basic evolutionary and ecological aspects of the genus are still unknown. The latest taxonomic revision revealed 16 valid species distributed worldwide; however, descriptions of most species are incomplete by modern standards and phylogenetic analyses are nonexistent. Our study will address whether this emerging model organism is actually a single cosmopolitan species, a group of cryptic species, or simply insufficiently described taxa. To test these hypotheses, this project will examine the structure of this group of sea anemones from the population to the family level. More than 500 individuals within the genus *Aiptasia* have been collected through an extensive sampling effort that encompasses the entire distribution of the 16 currently-described species. A taxonomic revision of the group has been conducted using morphological characters. A robust phylogenetic hypothesis based on 3 mitochondrial and more than 10 nuclear markers (most of them newly-developed for this study), which includes most members of the family Aiptasiidae, has been constructed using this newly-collected material. Additionally, population structure within *A. pallida*, *A. californica* and *A. pulchella*, as revealed by 16 polymorphic microsatellite loci specifically developed for this project, will be discussed.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1715, Sebel Tully

The role of peripheral endemism in species diversification

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We examined how peripherally isolated endemic species may have contributed to the biodiversity of the Indo-Australian Archipelago biodiversity hotspot by reconstructing the evolutionary history of the wrasse genus *Anampses*. We identified three

alternate speciation models: the vicariance-based 'successive division' model, and the founder based 'successive colonization' and 'peripheral budding' models. The genus was well suited for this study given its relatively high proportion (42%) of endemic species, its reasonably low diversity (12 species), which permitted complete taxon sampling, and its widespread tropical Indo-Pacific distribution. Monophyly of the genus was supported by three phylogenetic analyses: maximum parsimony, maximum likelihood, and Bayesian inference based on mitochondrial CO1 and 12S rRNA and nuclear S7 sequences. Estimates of species divergence times from fossil-calibrated Bayesian inference suggest that *Anampses* arose in the mid-Eocene and subsequently diversified throughout the Miocene. Evolutionary relationships within the genus combined with limited spatial and temporal concordance among endemics offer support for all three alternate speciation models. Our findings emphasize the importance of peripherally isolated locations in creating and maintaining endemic species and their contribution to the biodiversity of the Indo-Australian Archipelago.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1000, Sebel Tully

Central-peripheral hypothesis across reef organisms along the Ryukyu Archipelago

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Genetic variation is informative for understanding the mechanism of maintenance and formation of populations. The Ryukyu Archipelago is formed by many isolated islands and is located at the northern limit of the distribution of many reef benthic organisms, suggesting that it is difficult for the organisms to be connected through short-step dispersal. Furthermore, the populations of reef organisms around the Ryukyu Archipelago are expected to be often exposed to environmental stresses, leading to a reduction in population size followed by the loss of genetic diversity. On the other hand, along the Ryukyu Archipelago, the Kuroshio Current flows from south to north, and genetic homogeneity of populations is expected to be enhanced by the main current and it's eddies. To reveal how populations of reef benthic organisms are formed and maintained along the Ryukyu Archipelago, we are performing population genetic analyses by targeting some reef benthic organisms (corals, mollusks, echinoderms). In this presentation, I report the patterns of genetic variation of our target species along the Ryukyu Archipelago and discuss the mechanism of maintenance and formation of marine populations in this area.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1215, Sebel Tully

Recording reefs with Darwinian questions: historical studies on the Brazilian coast

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The objective of this research is to gather empirical information to emphasize the insertion of the Northeast Coast of Brazil into the North-American Darwinian discussion, especially the zoology of its coral reefs. References to the subject are found in descriptions produced by the Stanford Expedition to Brazil, 1911. The Expedition was directed by John Branner, a geologist that worked for a long time with David Jordan, zoologist at Stanford. They worked with models of speciation, and their scientific practices included a variety of natural science methods: biogeographic records, systematic taxonomy (distribution laws), ecological perspectives and collaborative research (biology and geology). This expedition recorded the biogeography of marine life to understand the role of isolation on the divergence in characteristics of species separated by a natural barrier. The taxonomy developed by these studies provides a body of knowledge that has acted as a bridge between old-fashioned natural history and modern field systems. This kind of field work integrates descriptive activities with qualitative models. Today, the results of the Expedition are reflected in many scientific institutions in North America, including biological collections and bibliographies. These collections are important biological records about the Brazilian reefs, and they are indicative of the relevant scientific Darwinian work made by this Expedition in the period known as the 'eclipse' of Darwinism. Thus, we attempt to analyze all these references as a whole, placing emphasis on both the practical science and the history documented in the records of Brazilian coral reefs.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1245, Sebel Tully

Demographic consequences of Pleistocene climate fluctuations on lagoonal specialist invertebrates

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LABEX CORAIL - USR 3278 CRIOBE-CNRS-EPHE

Pleistocene and Holocene sea level fluctuations have led to the extirpation of most inner reef obligate marine species. These events leave genetic evidence of demographic perturbations that we investigated in 14 populations of the black lipped pearl oyster, *Pinctada margaritifera* in the Eastern Pacific in general, and across French Polynesia archipelagos in particular. *P. margaritifera* has a distribution mainly restricted to high island or atoll lagoons. Using a strict molecular clock approach and fossil occurrence we estimated substitution rates of one mitochondrial and two nuclear markers. Coalescent methods revealed that *P. margaritifera* populations have undergone recent sudden expansion events resulting from wide founder effects and/or bottlenecks, between 2500 and 1000 years BP. These dates correspond to the end of the

last Holocene glaciations events when the sea level reached its actual level. Nuclear sequences appeared to evolve faster than mitochondrial (5.2% and 1% mean sequence divergence per million years, respectively) and showed that populations are gradually reaching equilibrium again thanks to high connectivity levels. In contrast, populations occurring in sites devoid of barrier reefs, and which are thus able to shift down slope with the sea level drop, like in the Marquesas or Papua New Guinea, remained stable in time and show genetic signs of refuge areas and source populations for the recolonization of the lagoons. By combining both mitochondrial and nuclear data we were able to recover the complex demographic history of this inner reef specialist bivalve in close relation with habitat availability.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1500, Sebel Tully

Biology and geography determine population connectivity in coral reef fish

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Which factors are most important in shaping population connectivity and whether their influence is consistent across species and seascapes remains unresolved. My research takes a comparative genetic approach to investigate the influences of seascape topology (past sea level changes, contemporary oceanography, and geography) and species biology (early life history characteristics and habitat specialisation) on coral reef connectivity around Australia (including parts of the Coral Triangle) and the South West Pacific. I focus on five common, co-distributed coral reef fishes that differ in early life history characteristics and degree of habitat specialization (*Pomacentrus coelestis, Dascyllus trimaculatus, Halichoeres hortulanus, Acanthurus triostegus* and *Apogon doederleini*). Mitochondrial sequences for each species were analysed to reveal species specific, and biological trait specific (i.e. egg type, habitat specialization, pelagic larval duration) patterns. Each species-specific dataset was then standardized, to reveal patterns common across species as a consequence of seascape topology. Both species biology and seascape topology influenced the patterns of population connectivity across the study area. The degree of connectivity within species was strongly influenced by egg type (benthic versus pelagic); species with pelagic eggs generally had greater population connectivity. The Torres Strait approximated the weakest connection among populations of most, but not all species (e.g. *A. triostegus*). Analysis of this dataset is on-going and will be combined with data from co-distributed invertebrate species in order to understand general patterns of coral reef connectivity.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 0945, Sebel Tully

Caribbean, Brazil, and West Africa: transatlantic evolution of corals revealed by molecular phylogenetics

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The concentration of reef corals in the tropical Indo-West Pacific and in the tropical Western Atlantic is one of the most well-documented patterns in biology, yet only a few studies have investigated the evolution of corals on an ocean-scale perspective. In this study, we use mitochondrial rDNA 16S and nuclear rDNA 18S to investigate the evolution of tropical shallow-water lace corals (Cnidaria: Hydrozoa: Stylasteridae) and fire corals (Cnidaria: Hydrozoa: Milleporidae) in space and time. Both groups span almost the entire range of coral life histories: lace corals are small, azooxanthellate, and brooders (with benthic crawling larvae), whereas fire corals are large, zooxanthellate, and disperse by short-living planktonic medusoids. For the lace coral genus *Stylaster*, our results reveal a vicariance pattern of speciation congruent with the establishment of the IWP-Atlantic, America-West Africa, and Brazil-Caribbean biogeographic barriers. Our results also indicate high population structure in Brazil and West Africa (at scales <100km in the Gulf of Guinea) and reveal that Brazilian populations of '*Stylaster roseus*' may represent a previously unrecognized species of coral. In contrast, results for the fire coral *Millepora alcicornis* reveal a single amphi-Atlantic species with low genetic diversity in Brazil and West Africa. This result suggests a range expansion to Brazil and West Africa (Cape Verde) from an older Caribbean source population. Our results, based on species with contrasting life histories, provide some of the strongest evidence to date that the Amazon River outflow if a powerful yet semipermeable biogeographic barrier for reef corals.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1230, Sebel Tully

Higher level systematics of Holothuroidea

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The higher-level systematics of sea cucumbers (Holothuroidea) are currently in a neglected state. The monophyly of most higher level taxonomic groups and their inter-relationships remain uncertain. As part of the NSF-sponsored Assembling the Echinoderm Tree of Life Project (http://echinotol.org/), we will use phylogenomic

methods based on transcriptome profiling to develop the most comprehensive Holothuroidea phylogeny to date. We are sampling widely, from the shallow reefs of Malaysia to the deep regions of Antarctica to construct complementary DNA (cDNA) libraries (via transcriptome profiling) from rare and seldom collected species. Molecular and morphological phylogenetic analyses of circa 200 exemplars, including fossil taxa, will be used in conjunction with previously developed data sets to redefine higher taxa. We seek to resolve the monophyly of all subclass through most family-level relationships. Preliminary results indicate that the orders Elasipodida, Aspidochirotida, and Dendrochirotida, as well as the subclasses Dendrochirotacea and Aspidochirotacea, are probably non-monophyletic. This indicates that the higher level taxonomy of the class requires major revision. Our full analysis will enable us to resolve relationships between the deep branches within Holothuroidea, an essential preliminary step to understanding a variety of other systematic and comparative evolutionary questions.

3A Evolution, biogeography & taxonomy
P012

Phylogeography and genetic aspects of zooplankton biodiversity in Southeast Asia

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Southeast Asia is considered to be one of the most geographically complex regions and is known as the center of marine speciation and biodiversity in the Pacific. The region encompasses highly diverse marine habitats, represented by coral reefs, mangrove forests, sea-grass beds, estuaries and deep margin basins. However, the area has also been identified as a serious hotspot of biodiversity crisis owing to human activities (pollution, fragmentation and decline of habitat) and climate change. Under this circumstance, there have been concerns about the urgent need to assess the present status of the health of the coastal ecosystems in Southeast Asia. The advancement of molecular techniques has expanded phylogeographic foci to not only study recent distributional patterns based on historical events, demographic factors, and dispersal barriers, but has also aided in conservation management and the investigation of invasive species, as well as serving as a tool for DNA based taxonomy for discovering cryptic species. We study the following issues: phylogeography and genetic population structure of, among other things, marine zooplankton. We used sequence data from the cytochrome oxidase I (COI) region of mitochondrial DNA (mtDNA). The results show differences in diversity occurred at geographical scales, and question ideas about the origin of the biodiversity. Some of the oceanic events were indicated as the mechanisms of speciation, however, there are questions that still remain unresolved: the exact time and time scale of such diversification events. These questions are among the major topics in general biodiversity studies, as well as in pelagic biodiversity in particular.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1515, Sebel Tully

Evolutionary mechanisms and diversity in a western Indian Ocean center of diversity

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The biogeography and evolutionary history of the shallow marine fauna in the western Indian Ocean (WIO) is poorly known, nor are the consequences of ancient and recent biodiversity-generating processes. In-water surveys of scleractinian corals show maximum diversity in a core region centered on the northern Mozambique Channel (NMC). Central Tanzania and northern Madagascar have the highest species richness (>300) with a threshold of 250 species differentiating this core region from lower-diversity zones in the Mascarene islands, northern Tanzania and Kenya, and small islands. Species and genus distributions show significant clustering of sites within this high diversity core region, distinguished from peripheral regions. From other workers, species richness of corals and other taxa, and genetic diversity within taxa, are supportive of the same pattern. A heritage of ancient evolutionary mechanisms is suggested by a distinctive WIO endemic fauna of monospecific genera and species with apparent Tethyan or Atlantic affinities. The Mozambique channel is the oldest part of the Indian Ocean (180my), with the most dramatic changes occuring from about >45mya. The dominance of Indo-West Pacific species in the extant coral fauna shows the influence of the South Equatorial Current in recent connectivity (<20my). Combining these with Reunion hotspot activity (<67mya), and fluctuating sea levels (<3mya), suggest the NMC may have been a refuge for tropical species throughout its history, with fluctuating connectivity first with the Tethys(/Atlantic), then the Pacific Oceans. This deep evolutionary history suggests a unique biodiversity across multiple taxonomic levels in this second peak of tropical marine biodiversity.

3A Evolution, biogeography & taxonomy
Friday 13 July, 1030, Sebel Tully

Was *Symbiodinium* Clade D introduced to the Caribbean?

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Stress induced coral bleaching leads to the widespread degradation of coral reef communities. However, some coral-dinoflagellate combinations are resistant to environmental stressors and their

proliferation may influence the response of reef communities to climate change. The stress-tolerant *Symbiodinium trenchi* (type D1a) is unique among the members of Clade D because it associates with a broad diversity of host taxa and has a global distribution. Recently, Caribbean populations of *S. trenchi* appear to have increased in prevalence and abundance in coral communities under prolonged exposure to abnormally high sea surface temperatures. The unique ecology and distribution of this symbiont prompted an investigation into its genotypic diversity and distribution in reefs from the Indo-Pacific and throughout the western Atlantic using twelve diallelic microsatellite loci. Populations of *S. trenchi* from the Indo-Pacific were genetically diverse with most genotypes the product of sexual recombination. In contrast, populations in the greater Caribbean were excessively clonal with low allelic diversity. While no multilocus genotypes (MLGs) were shared among sites in the Indo-Pacific, one prevalent MLG was found throughout the Caribbean. Genotypic diversity is usually high among populations of other Caribbean *Symbiodinium* spp. suggesting something unusual about the population dynamics and dispersal of *S. trenchi* in this region. We hypothesize that *S. trenchi* in the Caribbean stems from a small number of opportunistic introductions of Indo-Pacific origin and that the expansion of a particularly aggressive clonal lineage and/or population was facilitated by severe thermal anomalies occurring since the mid 1980's.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1145, Sebel Tully

Dispersal shapes micro and macroevolutionary diversity of reef fishes

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Reductions or interruptions in gene flow are central to the divergence of populations and species. Yet, no single biological trait affecting gene flow has been demonstrated to affect both micro and macroevolutionary patterns of diversity. A simple dichotomy of dispersal-related traits is found in reef fishes, where some fishes guard negatively buoyant eggs and others release small pelagic eggs directly into the water column. Here, we show that taxonomic families of benthic guarders have significantly greater population genetic structure and species richness than pelagic spawners, and that species richness per family is significantly correlated with mean population structure. These results illustrate that key traits associated with dispersal can shape both micro and macroevolutionary patterns of biological diversity.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1015, Sebel Tully

Phylogeography of *Acropora tenuis* in north Western Australia

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Coral reefs in Western Australia stretch for more than 3000 km along a similar latitudinal range to the Great Barrier Reef on the east coast. Unlike the Great Barrier Reef, however, coral reefs in Western Australia are disjointed and reefs are often separated by 400 km. Reefs on and off the north-west continental shelf have varying histories of contraction and expansion associated with fluctuating sea levels during glacial maxima and inter-glacial periods, which is expected to have left genetic signatures on marine species in this region. This study investigates the historical connectivity underlying contemporary distribution of the scleractinian coral *Acropora tenuis* in north Western Australia. Population genetic structure was compared using DNA sequence data from one mitochondrial and two nuclear genes from seven geographic populations of *A. tenuis* on and off the continental shelf, to determine evolutionary and contemporary levels of gene flow in this widely distributed species.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1200, Sebel Tully

Patterns in the diversity of coral reef fishes in the Western Indian Ocean

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Coral reefs are one of the most diverse ecosystems on the planet. Patterns in the diversity of coral reef fishes can provide insights into the effects of climate change (coral bleaching) and fishing against a backdrop of evolutionary biogeography. Teasing apart these global, local and historic drivers is critical for understanding present patterns in biodiversity and thus how to focus conservation action on coral reefs. We tested the hypothesis that there is a biodiversity centre in the Western Indian Ocean (WIO) and explored underlying causes of species distributions. We surveyed 19 families of reef associated fishes in Tanzania, Comoros, Madagascar and Mozambique, through a standardised dive based protocol. In total 354 species were registered in the study area. Using indices of diversity we found the total number of species was highest in Mozambique and Tanzania while taxonomic diversity was highest in Comoros. Community structure of fish assemblages in Comoros and Madagascar are different from eachother and the continental mainland. Present day oceanographic processes driving larval recruitment combined with speciation history are likely to explain the patterns. The diversity or functional attributes of fish communities also show changes in community structure in relation to substrata and anthropogenic influences. Analysis of

similitude of species reveals principal species that account for diversity patterns and provides representative species for geographical zones. The relationship between these zones and historic speciation patterns will be discussed in the context of linkages between Indian Ocean endemics, broad Indo-Pacific range species and the Red Sea/Arabian Gulf fauna.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1630, Sebel Tully

Phenotypic plasticity and speciation in octocorals: Caribbean Eastern vs. Pacific

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The Caribbean sea and the Eastern Pacific ocean have endemic octocoral faunas, the diversification of which apparently accelerated after the closure of the Isthmus of Panama. With a few seemingly allopatric-generated species, numerous closely related species of seven genera exhibit signatures of recent radiations. The different ecological settings of both oceans also suggest the possibility of these groups undergoing separate adaptive radiations. This hypothesis is based on phenotypic plasticity, which unravelled differently on alternate sides of the Isthmus. Zooxanthella-bearing Caribbean gorgonian corals exhibit community-wide patterns of phenotypic plasticity. Within each species, most individuals in shallow waters have smaller surface sclerites and shorter branches; several morphotypes are predator-induced phenotypes. Previous transplant experiments in *Eunicea flexuosa* and ongoing field experiments and genomic scans in *Pseudopterogorgia bipinnata*, suggest that phenotypic plasticity is related to genetic accommodation in gorgonian corals. Aposymbiotic gorgonians, comprising all the Eastern Pacific fauna, are suspension feeders, where form is optimized for capturing particular prey, as well as coping with currents and drag. *Muricea* has few symbiotic species in the Caribbean but more than a dozen aposymbiotic ones in the Eastern Pacific. The availability of new ecological opportunities created new niches for suspension feeding organisms, which could have driven adaptive radiations to exploit the new food sources in the Eastern Pacific. Gorgonian corals provide several examples where environmental conditions are related to diversification, which suggest a more important role of ecological speciation than previously thought.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1130, Sebel Tully

Phylogeography and morphometrics of the cleaner wrasse *Labroides dimidiatus*

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Marine cleaner fishes tend to have a dark lateral body stripe, which is considered an important cleaner signal that attracts client fish. Since cleaning provides cleaners with food and relative immunity from predation this stripe likely confers fitness benefits. Consequently, negative selection may remove individuals with less-recognisable stripes. Variability in the stripe of the cleaner wrasse *Labroides dimidiatus*, however, has been documented among and within populations across its distribution. Therefore, we investigated if variation within the stripe pattern was distributed geographically and/or concordant with genetic variation. We sampled at six sites across the Indian and Pacific oceans and obtained morphometric measures of the stripe, and used a partial sequence of the mitochondrial DNA control region for phylogenetic analyses. We found that the stripe pattern was significantly correlated with geographical location among sites. However, the narrow range of stripe variation suggests that the phenotypic evolution of *L. dimidiatus* is restricted by the cleaning mutualism, as the cleaner signal must remain recognisable to clients. Surprisingly, we did not find a correlation between the stripe and genetic distance matrices, consequently the stripe marking was not always useful for identifying genetic groups. An additional novel finding of our research, was that the inclusion of two closely related cleaner fish species *L. pectoralis* and *L. bicolor* in the phylogenetic analysis, renders *L. dimidiatus* polyphyletic, suggesting a complex evolutionary history for the group. Overall, the findings suggest the diversity within this species is significantly underestimated and may encompass cryptic species.

3A Evolution, biogeography & taxonomy
Thursday 12 July, 1545, Sebel Tully

The co-speciation between massive corals and gall crabs

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There are many invertebrates associated with the scleractinian corals. Despite a rich base of basic knowledge, these coral symbionts have received uneven attention with respect to their co-evolution

encompassing co-speciation and co-adaptation. Gall crabs in the family Cryptochiridae (Paulson, 1875) are obligate symbionts of corals, and can modify coral morphology by affecting growth (Simon-Blecher and Achituv 1997; Simon-Blecher et al. 1999). To study the co-evolution between symbionts and corals, we focuses on gall crabs living in corals and investigated the phylogenetic relationship between corals and gall crabs, using the mitochondrial COI marker. In the present study, we collected samples from six localities in temperate to subtropical regions of the Japanese coast. So far five species of gall crabs were found from three coral families Mussidae, Faviidae, and Pectiniidae. Our results of the molecular phylogenetic analysis revealed that the topology of the gall crabs was mostly concordant with that of the corals and that all five species of the gall crabs inhabit the specified coral hosts. These suggest that gall crabs have had co-speciation with corals. At present, taxonomy of corals species is confusing because of the lack of key characters to separate species. Existence of host-specific symbiotic organisms would help to understand taxonomy of coral species.

3A Evolution, biogeography & taxonomy
P014

3B Genetically-based species recognition: microbes to vertebrates

Molecular taxonomy reveals new *Echinometra* species

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Accurate assessment of species diversity is essential to nearly all areas of biology; studies of biodiversity, ecology, biogeography, conservation, and policy making all necessitate correct species identification. The eight cosmopolitically distributed species of the genus *Echinometra*, have long been used as model organisms in biogeographical and evolutionary studies and are often among the most prevalent urchins in the ecosystems where they occur. Four *Echinometra* species are reported from Okinawa, one of which, *E. mathaei*, is also reported from the Red Sea (RS) and Western Indian Ocean (WIO). However, in contrast to the well supported taxonomy of western Pacific *Echinometra*, little has been done in the RS and WIO. Here we examined the closely related Okinawan *Echinometra* as a model for evaluating the concordance between traditional and molecular taxonomy. The insights deduced from the Okinawan species were then applied to the taxonomic assessment of *Echinometra* from the RS and WIO. Our findings resulted in a contradiction of previous claims that all *Echinometra* in this region are *E. mathaei*. Furthermore, molecular taxonomy strongly supports our claim that these urchins are a new species. This conclusion is based on considerable molecular divergence from other *Echinometra* species, and their strongly supported monophily. Moreover, rigorous sampling conducted around the Island of Zanzibar and the northern Gulf of Aqaba suggests that no other *Echinometra* species exists in these regions. A clear biogeographic pattern therefore emerges between the Pacific and Indian Ocean populations with urchins from the RS and WIO being allopatric to those of the Pacific.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1530, Sebel Tully

Early ontogeny of cnidarian-algal symbioses: observations and future research directions

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Algal symbionts within the genus *Symbiodinium* form symbioses with a wide range of cnidarians. Although there is variation in symbiont type initially acquired by cnidarian hosts, there is still selectivity. As the symbiosis develops, specific host-symbiont pairings become apparent in most host species. We examined the role of various factors (environment, host genotype, etc.) in the establishment of the cnidarian symbioses. More specifically, we followed the initiation of symbiosis in a common scleractinian coral (*Montastrea faveolata*) and a common octocoral (*Briareum asbestinum*). Like many cnidarians these two species initially acquire a range of symbionts, up to nine *Symbiodinium* types at a single location. In *Montastrea faveolata*, environmental conditions may play a role as variation in symbiont uptake was observed among *M. faveolata* recruits maintained in different laboratory settings and in the field. In a laboratory setting, under low light, Clade D *Symbiodinium* was abundant after 6 months, while in a setting with higher light levels, Clade B *Symbiodinium* was the dominant symbiont type. Unlike reports for some species, *B. asbestinum* did not show a temporal or spatial pattern in the initial symbiont assemblage (i.e., those symbionts present after 3 months) suggesting that within the subset of symbionts that *B. asbestinum* recruits typically acquire, initial uptake is random. However, within 6-12 months, the assemblage is winnowed to a single dominant type which then changes to the adult type over 3-4 years. Furthermore, transplant experiments showed that the composition of final adult assemblage in *B. asbestinum* has a genetic component.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1500, Sebel Tully

Being yellow or brown: ecological and molecular base for colour adaptation in a marine fish

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Mimicry describes the biological phenomenon of a species to closely resemble another species in order to gain fitness. Although resemblance can be in a variety of traits such as in morphology or behaviour it generally refers to the imitation of model species pigmentation and patterning, making mimicry systems ideal to study convergent evolution among different species. Mimicry has traditionally been explored in invertebrate species though only little is known about how genotype is linked to phenotype in vertebrate mimicry species. Here, we investigate the genetics and genomics underlying phenotypic adaptation in *Pseudochromis fuscus*, a coral reef fish from the Indo Pacific. On Lizard Island, in Australia, the species has two distinct morphs, a brown morph and a yellow morph. The morphs are thought to be aggressive mimics imitating their respective prey species colouration. However, first results from an extensive field experiment revealed individuals from one colour morph are able to switch to the other colour morph. Much to our surprise, this plasticity seems to be triggered independent of associated model species colouration, and seems primarily to be driven by differences in microhabitat, suggesting multiple interacting forces to drive colour dimorphism in the species. We are currently using a variety of methods, including additional field and laboratory based experiments, theoretical fish visual modelling, and gene expression assays and sequencing, to ultimately reveal the selective forces driving *P. fuscus* colour adaptation and to investigate possible similarities on the molecular level of a vertebrate mimicry- model complex.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1645, Sebel Tully

Evidence of reticulate evolution in deep-sea bamboo corals

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ITS2 is one of the most widely used regions for molecular phylogenetic studies, however its value has been challenged due to intragenomic variation and the difficulty that the different copies impose in deciphering their origin. One possible explanation for ITS2 intragenomic variation is reticulate evolution of the species through a hybridization process. Reticulate evolution could produce additive patterns, where both parental types are present, or total copy homogenization toward one of the parental lineages. Given that deep-sea bamboo corals exhibit mito-nuclear discordance (one particular evidence for reticulate evolution), our main objective is to examine ITS2 sequences for the presence of additive polymorphic sites (APS), as additional evidence of a reticulate process. Genomic DNA was obtained from dry and ethanol-preserved coral tissue. Individual intragenomic variant sequences from ITS2 nDNA were obtained using DGGE and reamplification. ITS2 secondary structures were folded and an improved alignment was explored for APS. Additionally, phylogenetic relationships among specimens were obtained under MP, ML, and BI. The intra-individual copies were monophyletic for most of the specimens that presented more than one ITS2 copy, except for three samples where one of their copies was more closely related to other mitochondrial clades than to its own intra-individual group. There was evidence for APS for the three samples that showed great intragenomic variation. Intragenomic variation in ITS2 points to hypothesis of reticulate evolution in deep-sea bamboo corals, but additional evidence from mtDNA, morphology, ecology or reproductive biology is needed to support this hypothesis.

3B Genetically-based species recognition: microbes to vertebrates
P015

Changes in symbiont types in juveniles of the coral *Acropora tenuis* at different depths

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Establishment of symbiosis in early stages is important for reef-building corals to ensure nutrition. Coral eggs or planulae receive symbionts (*Symbiodinium* spp.) directly from their parents or acquire them from the environment. *Symbiodinium* are highly diverse and various lineages have been molecularly described. Although several studies show that early stage corals have several types of symbiont, little is known about the identity of *Symbiodinium* acquired during the early life stage under different environments. In the present study, we examined if aposymbiotic coral juveniles acquired multiple symbiont types at different depths (i.e., different light conditions) and how algal types changed over time. Newly settled polyps of *Acropora tenuis* were placed at two different depths (2m and 18m) near Sesoko Island, Okinawa (Japan). Juveniles were collected from each depth three weeks, 2, 4, 8 months and about 1 year after deployment. Adult colonies were also collected for algal type identification. The identity of *Symbiodinium* was established using fingerprint techniques of the ribosomal internal transcribed spacer regions (ITS2-DGGE). Multiple *Symbiodinium* subtypes from Clade A, C and D were detected in the juveniles from both depths. Moreover, one year after deployment, the juveniles still presented several *Symbiodinium* types

contrasting with a single type found in adult colonies (C3 type). The results indicate that the coral can acquire a variety of symbionts in their early life. Acquisition of various types during the juvenile is likely to increase survivorship by providing a continued source of energy. The association then gradually changes to adapt to local conditions.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1030, Sebel Tully

Population isolation and introgression in Eastern Pacific *Porites*

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Plastic morphologies and low mtDNA variation have hampered our ability to delineate coral species and recognize isolated populations. We used sequence data from five nuclear gene regions, mitochondrial DNA, and ITS sequences to infer species identity, population isolation, and geographic differentiation in inter-specific hybridization among corals of the genus *Porites* from Hawaii and the eastern Pacific. Previous analyses revealed strong incongruities between morpho-species and genetic lineages inferred from multi-copy ITS sequences, including cryptic species within well-studied populations of nominal *P. lobata* from the eastern Pacific. Bayesian cluster analyses based on microsatellite loci and allelic networks based on nuclear genes sequences generally agreed with ITS designations, although some individuals possessed one or two alleles at a particular locus generally associated with other species. Coalescent analysis of the two most abundant eastern Pacific species found no evidence of hybridization between them in Hawaii where they are morphologically distinct, but significant exchange since divergence in the eastern Pacific, where they are only genetically diagnosable. These results suggest introgression from *P. lobata* into *P. evermanni* may be responsible for their morphological identity in the eastern Pacific, and that repetitive ITS sequences may sort to effective monophyly at rates far faster than those for single copy nuclear markers, making ITS an effective tool for species delineation but a misleading one for inferences about the history of species isolation.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1630, Sebel Tully

Symbiont diversity in Vietnam: latitude, environment and host reproductive mode

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Vietnam faces a fast population growth combined with economic development resulting in high environmental pressures on the coastal ecosystems. The coast of Vietnam ranges over 3200 km in a north-south direction and covers two monsoonal regimes and 11 degrees of latitude (9°N to 21°N). Despite the high coral species diversity (locally between 189 and 404 coral species) the region is heavily understudied. In order to assess resilience and reef health in Vietnam, we identified the genetic composition (based on ITS2) and distribution of algal endosymbionts (*Symbiodinium* spp.) in a large number of coral species with different reproductive modes in inshore and offshore reef habitats along the latitudinal gradient. Our model showed that environmental factors (sea surface temperatures and a proxy for visibility (Chlorophyll *a*) derived from satellite data, latitude, regional measures of coral species diversity, depth, distance from land (inshore/offshore)) and reproductive mode were strong predictors for the distribution of symbionts. The diversity of symbionts increased within and between species in high coral diversity areas. The symbionts represented groups D and C, with one D type (D1a) and a large diversity of C types. The D1a symbiont exhibited an inshore- offshore zonation. In contrast; the different C symbiont types showed a strong latitudinal and regional distribution gradient, which shifted in dominance north to south. The study highlights the importance of identifying the different ITS2 types with varying ecological niches to further understand coral reef resilience. The consequences of the results and future studies will be discussed in more detail.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1730, Sebel Tully

Mitogenomic of medusozoans provides insights on the evolution of linear mtDNA in the group

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Improvements in sequencing technologies have yielded to an eruption of complete mitochondrial DNA (mtDNA) sequences from a majority of animal groups. Complete mtDNA provides an array of

phylogenetically informative characters, including sequence data, genome architecture, gene order, and genetic code. For instance, the structure of the mtDNA is a major molecular character used to subdivide the phylum Cnidaria into two large subgroups: Anthozoa (Octocorallia and Hexacorallia) where the mtDNA is a single and circular molecule, and Medusozoa (Cubozoa, Hydrozoa, Scyphozoa and Staurozoa) where the mitochondrial genome can consist of one, two or more linear molecules. Yet, until recently, only four complete linear mtDNAs were published for Medusozoa in comparison to 42 for Anthozoa. We explored the evolution of medusozoan mitogenomes by amplifying and sequencing nearly complete mtDNAs from species representing all four medusozoan classes. All medusozoan mitochondrial genomes sequenced are linear single or multipartite molecules harboring the expected number of genes for cnidarians. The presence of two extra ORFs (polB and ORF314) in most medusozoan groups allow us to infer that a single invasion event by a linear plasmid at the stem of medusozoan tree is responsible for the linearity of medusozoan mitochondrial genomes. Medusozoan mtDNA display a high rate of gene order conservation yet higher substitution rate relative to the circular molecules found in anthozoans. While such variations in substitution rates are challenging for inferring phylogenetic reconstructions between cnidarian classes, complete mtDNA sequences carry valuable information for resolving sister group relationships within each of the classes.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1115, Sebel Tully

The impact of species recognition on coral-dinoflagellate symbioses research

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Poor taxonomy leads to unclear or incorrectly interpreted patterns that limit and/or betray our understanding of ecological and evolutionary processes. New genetic data are frequently incongruent with traditional morphology-based systematics, and old taxonomies of many reef organisms including microbes, invertebrates and vertebrates require revision. The ability to accurately delimit diversity into natural and reproductively isolated, independently evolving, groupings (i.e. species) remains a challenge, but nucleotide sequence and population genetic data in combination with more traditional approaches offer a long awaited standardization for species identification/recognition. In the research of coral-dinoflagellate symbioses, there are a growing number of examples where improved accuracy in taxonomic resolution of both the host and the symbiont drastically alters perceptions of diversity, biogeography, reproductive biology, ecology, and evolution. The development of well-supported genetically based taxonomic and systematic schemes for these and other groups of reef organisms will significantly improve the quality of knowledge and advance the pace of future scientific investigations.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1000, Sebel Tully

Can corals evolve new zooxanthellae preference?

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Numerous studies suggest that the specificity of the association between coral and zooxanthellae could be the major factor responsible for the variation in corals' bleaching resistance. The specificity of early symbiosis is of particular relevance, since the type of zooxanthellae initially taken up by a young coral recruit does not change for several years and strongly influences survival. Surprisingly, the current literature suggests a lack of symbiosis specificity in coral juveniles, indicating that the evolution of new coral-zooxanthellae associations might be driven exclusively by natural selection on zooxanthellae. Here, we investigated whether there is a host-derived genetic component to symbiosis specificity at the early stages of the coral's life cycle, and whether there is any heritable variation of this trait in natural populations. We performed 20 crosses between 5 individual colonies of *Acropora millepora* in a full diallel design, reared larvae to settlement competence, and settled them on microscope slides. The slides with young recruits were kept in a flow-through raceway with unfiltered seawater in the presence of several adult corals and reef sediment until most of the recruits acquired zooxanthellae. Proportions of different zooxanthellae genotypes (clades A, C, and D) within each cross were quantified by sequencing the ITS-1 amplicons using 454 (>1000 reads per cross). Substantial additive genetic variation was observed, indicating that genotype of the host does play a role in determining the symbiosis specificity, and therefore the evolution of new symbiotic associations may be driven by natural selection on the coral host.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1215, Sebel Tully

Development and testing of molecular barcodes for Octocorallia

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Unusually slow rates of mitochondrial gene evolution have hindered the development of molecular barcodes capable of discriminating among species of Anthozoans. In a previous study, we reported that a mitochondrial COI+msh1 barcode effectively identified about 70% of shallow reef octocorals collected in a regional biodiversity survey in the Red Sea. We have now tested this barcode further and compared it to a potential nuclear barcode (~750 bp fragment of 28S rDNA) in a survey of shallow reef octocorals in Palau. The number of species detected using molecular criteria was very comparable to estimates of octocoral biodiversity from recent surveys of Palau that had been conducted using traditional taxonomic methods to identify species. Within the speciose, taxonomically challenging genus *Sinularia*, we correctly identified 85% of 52 specimens to known species using a molecular barcode in conjunction with comparisons of in situ photographs of colonies to reference images. 28S rDNA discriminated species of *Sinularia* approximately as effectively as COI+msh1, but low levels of polymorphism and amplification of apparent pseudogenes complicate the use of this nuclear gene as an alternative barcode. Although lineage-specific differences in rates of mitochondrial gene evolution suggest that COI+msh1 will be more effective for species discrimination in some groups of octocorals than others, use of this imperfect barcode nonetheless greatly facilitates identification of reef octocorals and reduces the need to employ taxonomic specialists for routine biodiversity survey work.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1130, Sebel Tully

Biodiversity forensics: what do genetic barcodes tell us about echinoderms?

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Coral reefs are one of the most endangered marine ecosystems and yet, estimates for the number of species associated with reefs vary by an order of magnitude. Molecular taxonomy can greatly speed up screening for diversity and evaluating species boundaries. DNA barcoding with a region of cytochrome oxidase 1 (COI) is now widely used as a first pass for molecular evaluation of diversity, as it has good potential for identifying cryptic species and improve our understanding of marine biodiversity. We present the results of a large scale barcoding effort for echinoderms, focusing here on asteroids, echinoids and holothuroids. We sequenced over 3,900 individuals from numerous localities across the Indo-Pacific and the Caribbean. Many species show genetic differentiation between ocean basins, and some are even differentiated among archipelagos. The number of cryptic species is much higher than currently recognized. The vast majority of sister species have allopatric distributions. Interestingly, many closely related and sympatric forms which exhibit distinct color patterns and/or ecology show little differentiation in and cannot be separated by COI sequence. This pattern is much more common among echinoderms than among molluscs or arthropods. This suggests that echinoderms (1) diversify at a much faster pace than other marine phyla; (2) are characterized by much higher levels of introgression; or (3) present higher levels of polymorphism. Understanding the causes behind such pattern will refine our understanding of diversification and biodiversity among echinoderms.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1515, Sebel Tully

Consideration of reticulate evolution on the genus *Palythoa*

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The zoanthid genus *Palythoa* is found worldwide in coral reef ecosystems. Although their classification has been in confusion, owing to recent molecular phylogenetic analyses, species identification is becoming clearer. Furthermore, previous studies have implied that reticulate evolution may occur between the species *P. tuberculosa*, *P. mutuki* and *P.* sp. yoron. In addition, a putative fourth species in this complex, *P.* aff. mutuki, has recently been found sympatrically in Japan with the other three species. In this study, we attempt to clarify the relationships among these four species by phylogenetic analyses and investigation of spawning timing. Observation of in situ colonies and specimen collection was performed in 2010 at Tokunoshima and Yoron Islands, Kagoshima, Japan. *Palythoa tuberculosa* spawned from the middle of August and *P.* sp. yoron spawned after September while no gonad development was observed in *P. mutuki*. Many additive polymorphic sites (APS) were found in the internal transcribed spacer alignment of ribosomal DNA (ITS-rDNA) of *P.* aff. mutuki, and some APS were in common with only *P.* sp. yoron. These data indicate that *P.* aff. mutuki could be the product of hybridization between *P. mutuki* and *P.* sp. yoron, supporting the hypothesis that reticulate evolution has occurred among these four species. To further clarify their relationships, how and when *P. mutuki* reproduces may be a critical key. An understanding of the mechanism of reticulate evolution in *Palythoa* will help us understand why this genus is apparently speciose, and yet most species are apparently closely related.

3B Genetically-based species recognition: microbes to vertebrates
P016

Host-symbiont interactions at the sub-clade level influence holobiont thermal resistance

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Previously unexplained phenotypic variation within coral species might be accounted for by genotypic differences among symbiont strains. Data from highly variable genetic markers such as microsatellites can now address this hypothesis by providing genotype-level resolution in both partners and so further our understanding of cnidarian-dinoflagellate symbioses. Adult Caribbean *Acropora* spp. harbor only one symbiont type: *Symbiodinium fitti*. Further, in most cases (ca. 90%), adult colonies harbor only one clonal strain (genotype) of symbiont. This sets the stage to test how the combinations of host and symbiont genotypes influence the performance of the holobiont. In natural and artificial common garden experiments with Caribbean Acroporid corals, we investigated how host genotypic variation influences performance of *S. fitti* genotypes and the holobiont. We observed up to 3.9-fold differences in daily growth between distinct host genotypes sharing a single, identical symbiont genotype. Further, up to 2.7-fold differences in photosystem II pressure were observed among identical symbionts in different host genotypic backgrounds when exposed to temperature stress. Such variation was mirrored in measurements of mitotic indices and growth rates among distinct *Symbiodinium* cultures under heat stress. We further targeted holobionts that had different susceptibilities to hot- and cold-water bleaching in the wild. Ongoing analyses of host gene expression in these experimentally heat-stressed holobionts are revealing both conserved and specific molecular responses. Together, these results indicate that the unique combination of host and symbiont genotypes provides a significant source of physiological variation in corals that may serve as a foundation for thermal adaptation.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1230, Sebel Tully

Biodiversity of coral reef zoanthids: how many species?

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Zoanthids are an order of hexacorals (Cnidaria: Anthozoa) closely related to sea anemones, with the suborder Brachycnemina ecologically similar to reef-building scleractinian corals in that they are both colonial and zooxanthellate (with endosymbiotic *Symbiodinium* dinoflagellates). Despite their commonness in subtropical and tropical coral reef ecosystems, their taxonomy and identification has historically been confused due to a lack of diagnostic morphological characteristics and large amounts of intraspecific variation. However, recent studies utilizing molecular techniques have allowed reconsideration of zoanthid species diversity. In this study, the results of molecular and morphological examinations of zooxanthellate zoanthids are combined with a comprehensive review of the historical literature (in the World Register of Marine Species) to estimate the total number of species within the suborder Brachycnemina. Results show that the while it is likely undiscovered species do exist, many species in *Palythoa* and *Zoanthus* are likely synonyms, and the total number of species in these two genera is likely much lower than the current 400+, perhaps by an order of ten. As more and more species are confirmed to be synonymous, the future of coral reef nomenclature will undoubtedly see massive revision, as the pace of confirmation of species identities using DNA markers while revisiting original descriptions, increases.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1015, Sebel Tully

The intrageneric classificaion of Melithaeidae

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The family Melithaeidae is a group of gorgonian octocorals belonging to the order Alcyonacea. They are considered to show unique colonization as they are dominant in environments where almost no other octocorals exist, for example on the roofs of caves and on the surface of pillars. However, research on their distribution and ecology are lacking, primarily because of the extreme difficulty in distinguishing between species. The most important morphological diagnostic character in all alcyonaceans is the shape of sclerites at anthocodia, calyx and in the cortex. However, in Melithaeidae, a variety of sclerites are found in each part. Recently, phylogenetic analyses focusing on Melithaeidae have been conducted for specimens from the Ryukyu Island. These studies found that there was a relationship between the shapes and types of sclerites at the cortex, and the family phylogeny. However, interspecific relationships were not clearly observed, as both DNA markers utilized, COI and 28S-rDNA, are relatively slow-evolving and likely not suitable for species-level identification in Melithaeidae. In this study, we examined the utility of the internal transcribed spacer of ribosomal DNA (ITS-rDNA), which has successfully been used as a species-level marker in other groups of Alcyonacea. Results were examined with morphological characters to assess which characters reflect ITS-rDNA phylogeny. It is hoped the results of this study will provide a methodological foundation for species identification

that will subsequently advance Melithaeidae research.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1700, Sebel Tully

Host-specialist lineages dominate the adaptive radiations of endosymbiotic dinoflagellates (*Symbiodinium*)

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Adaptive radiations have occurred throughout the history of life. Many of these bursts of diversification occur when populations differentiate from a common ancestor through ecological specialization. Clade C *Symbiodinium* is the most diverse and ecologically dominant group of endosymbionts (zooxanthellae) found in corals. In the Caribbean, phylogenetic reconstructions based on rapidly-evolving non-coding sequence data from plastid psbA mini-circle, and supported by nuclear ribosomal DNA spacer regions, identified numerous independent monophyletic lineages, each comprising haplotypes associated with specific host taxa. Portions of these lineages are further differentiated by geographic region. The level of genetic divergence between *Symbiodinium* clade C lineages is indicative of high species diversity according to ecological and phylogenetic species concepts. When compared to counterparts from the Indo-Pacific, this clade appears to have undergone a major diversification from a common ancestor beginning in the late Miocene-early Pliocene as the planet grew cooler and carbon dioxide levels reached their lowest levels in 300 MY. These lineages and the specificity they display therefore appear long-lived and most are probably incapable of associating with different hosts in response to climate warming.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1200, Sebel Tully

Delimiting species of *Symbiodinium* with concordant genetic data

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A large diversity of *Symbiodinium* lineages with distinct ecological and biogeographical distributions have been distinguished using nuclear ribosomal transcribed spacer sequences (ITS 1 and 2). Formal species assignment based on these data, however, remains a subject of controversy. Through the analysis of microsatellite markers and sequence data from the non-coding region of the psbA mini-circle, we evaluated population and phylogenetic data under the assumption of panmictic mating across lineages with nearly identical ITS sequences. Based on numerous examples, we found that geographically distant populations of *Symbiodinium* that shared the same ITS sequence contained similar allelic compositions relative to sympatric populations differentiated by slightly different ITS sequences. Together, these data indicate that species of *Symbiodinium* can be defined based on criteria that satisfy the biological, phylogenetic, and ecological species concepts, and that there are hundreds of morphologically cryptic yet genetically divergent *Symbiodinium* spp. awaiting description. These findings further substantiate a growing awareness that these microbial eukaryotes are considerably more diverse than current assessments indicate.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1715, Sebel Tully

Morphological variation and reproductive success of branching *Acropora*

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Branching *Acropora* corals constitute one of the major habitats in coral reefs, especially as fish nurseries on tropical coasts. However, the biological and ecological research regarding these corals, is still in progress, and taxonomy needs reexamination. We compared the morphological variations and reproductive success of cultured and wild colonies of branching *Acropora* corals. *Acropora intermedia* is a one of the dominant branching species in the Indo-Pacific reefs. Although colonies of *A. intermedia* without any morphological variations were collected, two morphotypes were observed during the long-term culture in aquarium. In this study, morphological comparisons, cross-experiments and DNA analysis were conducted using the morphotypes and wild specimens in order to reexamine the species status of *A. intermedia*. To compare the morphological variations between the two cultured morphotypes and wild specimens, we took microphotographs of the skeletal specimens using a digital microscope and measured the width (diameter) and height of axial and radial corallites. To identify the existence of reproductive isolation between them, the genetic relationships were analyzed using microsatellite marker and AFLP, and also cross experiments were conducted in 2010 and 2011. The result of cross experiments revealed that the two morphotypes fertilized successfully (20/20 in 2010, 30/34 in 2011). The results suggested that *A. intermedia* has multiple morphotypes rather than cryptic species. In the presentation, we discuss about whether the morphotypes of *A. intermedia* resulted from environmental adaptation or intra-specific genetic

variations, and also, we try to revise the species status of the dominant branching *Acropora* around Japan.

3B Genetically-based species recognition: microbes to vertebrates
P017

Acropora corals select preferable *Symbiodinium* clade in early symbiosis stages

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The dinoflagellate genus *Symbiodinium* (referred to as zooxanthellae) is a symbiont of corals, and has been divided into nine phylogenetic clades A~I which may have physiological distinctions. Offspring of *Acropora* corals must acquire *Symbiodinium* from the surrounding environments, and therefore, selection and acquisition of suitable *Symbiodinium* is crucial for their survival. To investigate whether corals actually select preferable *Symbiodinium* from the environment, we compared *Symbiodinium* clade compositions of corals and of the surrounding seawater in the field. Moreover, we tried to infect *Acropora* larvae with several *Symbiodinium* culture strains. The artificially and naturally settled recruits of *Acropora* corals were collected several times during May to November in 2009 and 2010, and 10-days before these samplings, ambient seawater were also collected. *Symbiodinium* clade compositions of these recruits and seawater were determined by clade specific PCR. For infection trials, each culture strain of clade A~F *Symbiodinium*, at a density of 1 cell/ml, was exposed to seven larvae of *Acropora tenuis*. After 24h, the larvae were observed under fluorescent microscope to confirm presence/absence of *Symbiodinium* cells. In the field surveys, the recruits mainly harbored clade A and/or D, while a few recruits (9% of 351 recruits) harbored clade C. In contrast, environmental *Symbiodinium* mainly consisted of clade C. This preference for clades A and D in the field recruits was supported by the infection test; *A. tenuis* larvae acquired clades A and D *Symbiodinium*. These results indicated that *Acropora* corals can select and acquire preferable *Symbiodinium* clades at early stages of their symbiosis.

3B Genetically-based species recognition: microbes to vertebrates
P018

Identification of a shell color-linked marker in the noble scallop

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The DNA amplified fragment length polymorphism (AFLP) fingerprinting approach was employed to identify a shell color-linked marker in the noble scallop *Chlamys nobilis* Reeve. The marker B1f176 was completely linked to the gene for bright orange shell color with no recombination in the progeny we sampled. This marker was amplified in bright orange parents and all orange progeny but was absent in all of the brownish-purple progeny. Nevertheless, AFLP markers are not feasible for large-scale application. Thus, we converted B1f176 into a sequence-characterized amplified region (SCAR) marker that we designated as SCAR Orange-142. The marker Orange-142, like the AFLP band from which it was derived, amplified a robust band in only the bright orange scallops, both in F1 and F2 families as well as in a test group obtained from a seafood market. These results indicate that Orange-142 is tightly linked to the gene for orange shell color. In all but one of ten F2 families derived from bright orange F0 grandparents, the observed frequencies of orange progeny were consistent with Mendelian ratios expected from a one-locus two-allele system in which the brownish-purple genotype was recessive. This study is the first report of the genetic basis for shell color in *C. nobilis*. The identification of a shell color-linked marker in the noble scallop improves our understanding of shell color inheritance and may contribute to *C. nobilis* brood stock enhancement programs using marker-assisted selection.

3B Genetically-based species recognition: microbes to vertebrates
Monday 9 July, 1145, Sebel Tully

3C The new age of integrated coral taxonomy

Evolutionary relationships within the family Dendrophylliidae based on morpho-molecular evidences

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Phylogenetic relationships among scleractinian corals have traditionally been investigated using morphological characters. Nevertheless, recent molecular analyses have demonstrated the low resolution of this approach and the use of poorly informative skeletal structures. Polyphyly and paraphyly are pervasive at all taxonomic levels and a re-evaluation of coral systematics is clearly needed on the basis of molecular evidence and new micromorphological characters. In this context the family Dendrophylliidae Gray, 1847 as currently recognized, is the only family that remains unchanged in composition with no new closely related genera or species from other families based on mitochondrial phylogenies. The family is comprised of genera characterised by very different

distributions, ecology, adaptations, and macro-morphology with few zooxanthellate genera and species, while the majority of its representatives are azooxanthellate and deep sea dwellers. We reconstruct phylogenetic relationships of the genera *Turbinaria* Oken, 1815, *Duncanopsammia* Wells, 1936, *Balanophyllia* Wood, 1844, *Heteropsammia* Milne Edwars and Haime, 1848, *Rhizopsammia* Verrill, 1869, *Leptopsammia* Milne Edwards and Haime, 1848, *Tubastrea* Lesson, 1829, *Dendrophyllia* de Blainville, 1830 and *Astroides* Quoy and Gaimard, 1827, on the basis of two mitochondrial and one nuclear marker. Our results confirm the monophyly of the family and point to numerous discrepancies with morphological phylogeny proposed for this family. The genus *Turbinaria* is basal and clearly polyphyletic with poor delimitation of species boundaries. *Turbinaria peltata* is highly divergent from its congeneric species and morphology confirms its misleading taxonomic collocation. Furthermore, molecular results provide the base for understanding several morphological character variations.

3C The new age of integrated coral taxonomy
Friday 13 July, 1245, Sebel Tully

Once were Faviidae: unexpected robust coral clades explained by morphology

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Molecular analyses showed that the Scleractinia consists of two major clades, Robust and Complex, and that most of the traditional families and genera are polyphyletic. Morphology-based systematics is hence being radically changed and different characters are found or rediscovered. However, some discrepancies between traditional and molecular groupings of taxa have not been investigated, and some genus type species have not been examined, thus taxonomic changes are left pending. Within the Robust clade, the family Faviidae is closely related to the Merulinidae, Mussidae, Trachyphylliidae, and Pectiniidae, and most genera from these families were retrieved in closely related clades. However, *Cladocora*, *Solenastrea*, *Oulastrea*, *Leptastrea*, and *Plesiastrea*, are not closely related to the Faviidae. In this study new molecular evidence that another former faviid genus, *Parasimplastrea*, and the type species of *Cladocora*, *C. caespitosa*, are not related to this family is provided on the basis of COI and rDNA phylogenies. Moreover, the polyp macro-morphology and the corallite micro-morphology of these six former faviid genera and of their new closest relatives were examined. Following an integrated approach some formal taxonomic changes are proposed. The family Oulastreidae Vaughan 1919 is restored and revised, and includes *Oulastrea* and different shallow water and azooxanthellate taxa. The genus *Parasimplastrea* is synonymised with *Blastomussa*. The genera *Cladocora* and *Solenastrea* are included in the family Oculinidae. In the case of *Leptastrea*, the striking morphologic differences with the closely related Fungiidae are examined in detail.

3C The new age of integrated coral taxonomy
Friday 13 July, 1200, Sebel Tully

How to identify species of the massive coral genus *Favia*

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Species identification is difficult in the zooxanthellate scleractinian coral genus *Favia* because of a lack of both reliable criteria for separating species, and information on morphological variation for species. Molecular-based phylogenetic analyses provide a strong tool to assist identification by inferring species boundaries. We collected more than 10 species from Japan and Australia and analyzed them genetically using the mitochondrial non-coding region. We cross-referenced examined samples with original descriptions and type material wherever possible. The molecular phylogenetic tree separated *Favia* clearly into three major groups according to the existence of indels: (1) *F. speciosa*, *F. pallida*, *F. matthaii*, *F. cf. speciosa*, and *F. cf. lizardensis*, (2) *F. favus*, *F. lizardensis*, *F. maritima*, *F. truncatus* and one undescribed species and (3) *F. maxima*, *F. rotumana*, *F. aff. veroni*, *F. cf. truncatus*, as well as *Goniastrea aspera*, *G. aff. palauensis*, and *Trachyphyllia geofferoyi*. Each group contained several clades. Treating a clade containing specimens with typical morphologies of the species as the species specific clade, gave the best resolution of separate species and allowed us to determine which morphological characters were most informative, and their variation within species. The results indicate that species of *Favia* will have morphological variations across species and occasionally become similar to each other. We concluded that, to identify coral species, the most important thing is to know the exact characteristics of the type specimens of each species and then to delineate the boundary between species using molecular analyses.

3C The new age of integrated coral taxonomy
Friday 13 July, 1230, Sebel Tully

A phylogenetic ecology of mushroom corals

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Phylogenetic models based on molecular techniques are not only useful for taxonomic purposes but also appear to be applicable as tools for comparative evolutionary analyses of ecological traits and life history features among closely related species. The phylogenetic relationships of the Fungiidae, a family of predominantly free-living reef corals, were reconstructed by sequencing a part of the COI and the ITS I & II markers of specimens from various Indo-West Pacific locations. Three major clades are distinguished, one of which consists of species with long tentacles. The other two cannot be clearly separated from each other morphologically. A loss of the ability to become free-living appears to have evolved independently as reversals in various separate clades. The evolution of corals with additional (secondary) mouths from corals with only a single primary mouth also appears to have occurred several times. Free-living polystomatous species are able to grow larger than their monospecific relatives, whereas encrusting species appear to be size-constrained. Comparisons of closely related species regarding their associated fauna, indicate that associations may be restricted to certain evolutionary lineages, whereas they may also be determined by ecomorphological traits, such as coral dimensions and polyp shape. In an evolutionary study of cross-shelf distribution patterns, offshore reef slopes appear to be ancestral habitats, whereas onshore habitats, reef flats and reef bases seemed to be derived. The latter is in contrast with a previous model, in which deep sandy substrates of reef bases were considered ancestral mushroom coral habitats.

3C The new age of integrated coral taxonomy
Friday 13 July, 1430, Sebel Tully

Evolution of coral macromorphology, microstructure and micromorphology in the 'Bigmessidae'

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The clade 'Bigmessidae' is an informal scleractinian grouping that comprises four conventional living families, Faviidae, Merulinidae, Pectiniidae and Trachyphylliidae. Recent molecular phylogenetic analyses have unequivocally shown that these families are not monophyletic. For instance, *Trachyphyllia geoffroyi*, the only extant Trachyphylliidae species, groups with Pacific *Favia*, while species of Merulinidae belong to two separate subclades within 'Bigmessidae'. These results call into question the use of morphological characters for defining taxa within the group. Yet, most 'Bigmessidae' genera are monophyletic (the exceptions being *Favia*, *Favites*, *Goniastrea*, *Montastraea*), and well-defined genus-level subclades appear to be supported by subcorallite morphological features. To determine morphological traits that are diagnostic of subclades within 'Bigmessidae', we mapped 48 characters onto an 82-species molecular phylogeny represented by 122 terminals. We examined the congruence between molecular data and morphology at both the corallite and subcorallite levels, the latter including microstructure (centers of rapid accretion and thickening deposits) and micromorphology (shapes of septal teeth, granulations and interarea). Although corallite characters (mean RI [retention index] = 0.69) exhibited more homoplasy overall than subcorallite ones (microstructure mean RI = 0.77; micromorphology mean RI = 0.77), several corallite traits such as the presence of intracalicular budding (RI = 0.93) and columellar continuity (RI = 0.86) revealed only limited homoplasy. Subcorallite morphology diagnostic of subclades include characters associated with wall microstructure, septal tooth axes and interarea (mean RI > 0.81). Our results indicate that, although most conventional morphologic characters are highly convergent, many less-studied traits are effective at distinguishing subclades and tracing their evolution.

3C The new age of integrated coral taxonomy
Friday 13 July, 1145, Sebel Tully

Synopsis of the Family Xeniidae (Cnidaria: Octocorallia): status and trends

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The family Xeniidae is a soft coral component of many shallow water tropical reefs throughout the Indian Ocean, Red Sea, South China Sea, Indo-Pacific and Eastern Pacific Ocean. There are 18 morphologically defined genera with a total of 163 species described to date. During an examination of xeniid octocorals held in the collections of the California Academy of Sciences (CAS) it was determined that identification to the species level was severely limited by most species descriptions published prior to 1950. A lack of consistent use of morphological characteristics by authors was found to be the most common difficulty, followed by limited or non-existent in situ data of the species being described. Descriptions from the later part of the twentieth century to the present offer more complete and detailed descriptions of species. This paper presents the status of the Xeniidae by reviewing its two hundred year taxonomic history, examines the worldwide distribution of xeniids to date, and identifies the current challenges in systematics. It provides an overview of trends in modern taxonomy including in situ data collection, molecular analysis, and scanning electron microscopy. This last technique illustrates the micro-structural features of the sclerites or skeletal elements, a major taxonomic character of octocorals including the Xeniidae. The modern

methods of taxonomic systematics outlined here are applicable for both xeniids and octocorals in general.

3C The new age of integrated coral taxonomy
P019

Climate change and the evolution of the Scleractinia

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Previous periods of global environmental change have resulted in mass extinction events (MEE) affecting all or most marine phyla. The synergistic and global impacts of atmospheric CO_2 concentration and fluctuations in both sea level and temperature have strongly influenced, and currently pose major threats to, calcifying organisms such scleractinian corals. Of the nearly 1500 known extant scleractinians, 50.7% are zooxanthellate and restricted to shallow-waters, whereas 48.5% are azooxanthellate and inhabit shallow and deep-waters (ubiquitous to all oceans) and only 0.7% are facultatively symbiotic. Despite a rich fossil record, particularly for zooxanthellate forms, the origin of the Order Scleractinia is still a topic of great controversy. Comprehensive molecular analyses, and consideration of the Paleozoic fossil record indicate that the oldest scleractinian lineages were azooxanthellate and solitary and that the Order probably had shallow-water origins but later 'invaded' deep waters. With the aim of better understanding how corals may respond to our rapidly changing climate, we investigated correlations between the key events in coral evolution and global climatic conditions over the past 460 My. Based on these analyses, we hypothesize that global environmental change has, to a large extent, shaped the evolution of scleractinian corals.

3C The new age of integrated coral taxonomy
Friday 13 July, 1115, Sebel Tully

Phylogeny and taxonomy of the genus *Goniopora*

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The genus *Goniopora* de Blainville, 1830 belongs to the family Poritidae, and is characterized mainly by the septal arrangements and the elongating polyps. Species of *Goniopora* sometimes become abundant and form an extensive communities, especially in bay areas and high latitudinal regions. But taxonomic studies have been scarce to date. In addition, diagnoses of species in this genus are obscured by large skeletal morphological variations within species, therefore there is an urgent need for advanced taxonomic study of *Goniopora*. In the present study, we collected more than 100 *Goniopora* colonies from 20 locations along the Japanese coast. First, we identified 14 species from these specimens based on morphological descriptions including original ones in the literature, but some colonies did not fit into any species descriptions. We also analyzed the specimens phylogenetically using mitochondrial COI and nuclear rDNA. Our results showed that the *Goniopora* specimens were separated into two major clades genetically, i.e. one consists of *G. stutchburyi* only and the other contains all other species. Notably the former clade made a sister group with *Porites*, suggesting that *Porites* had been derived from *Goniopora*. The latter clade was separated into five sub-clades consisting of one to several species. Comparisons of the skeletal characters of specimens within each sub-clade revealed that a few species should be integrated into one species while some are undescribed species. We also compared the morphology of polyps between species, but this approach did not seem to be useful to identify species because variations within a species were too large.

3C The new age of integrated coral taxonomy
P020

Effects of 2010 coral bleaching on reproductive performance of corals along the eastern coast of Thailand

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In 2010, coral reefs in the Andaman Sea and the Gulf of Thailand suffered the most severe bleaching event in their history, as sea surface temperature increased from 29 to 33℃ from March to June. The impact varied amongst sites, depending on coral community structure and reef location. Nationally, bleaching occurred between 30-95%, and in Rayong, eastern Thailand, bleaching occurred in all locations. *Acropora* and *Pocillopora* colonies showed 100% bleaching, but interestingly several juvenile *Acropora* colonies were still observed at all sites. In contrast, the bleaching of Faviidae and Mussidae was more variable, ranging between 10-80%. The major objectives of this study were to 1) examine the reproductive capabilities of surviving colonies following the bleaching event, and 2) to

evaluate the ability of recruit recovery. Firstly, we collected samples from tagged colonies for histology every four months from February 2011 to March 2012 at 6 sites in Rayong. Secondly, we observed new recruits in situ using settlement plates that were replaced every four months, and juvenile colonies were observed in permanent quadrates, where growth and survival were measured. Preliminary results indicate that only 20-40% of mature Faviidae and Mussidae colonies reproduced during February to March 2011. Mussidae recruits settled on plates between March and June 2011. Further analyses aim to identify the most vulnerable species and their reproductive effort by observing the development of gonads after bleaching, and identifying sites that have potential for recovery.

3C The new age of integrated coral taxonomy
P021

A morphometric and molecular characterization of Hawaiian *Leptoseris*

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Leptoseris has the deepest known distribution (165 m) among photosynthetic corals and is a dominant habitat-builder in mesophotic coral ecosystems (MCEs). The genus was revised as recently as 1980 using a traditional taxonomical approach. However, identification of species within the genus remains problematic because most species lack discrete diagnostic characters. Recent studies of Hawaiian *Leptoseris* have documented previously unknown morphologies and genetic diversity from deep-water samples (> 60 m). The present study will use a combined morphometric and molecular approach to test conventional species boundaries on Hawaiian *Leptoseris*. The goal is to improve the consistency of species identifications across the genus' full depth range and to characterize the vertical distribution of species in Hawaii. Samples were collected from 2 - 129 m and include a large number (n > 100) from > 60 m. Also included in the analysis are type and non-type specimens analyzed during a visit to the U.S. National Museum of National History. Coral skeletons have been photographed for corallite and septocostal morphologies using scanning electron and light microscopy. Diagnostic characters will be identified and morphometric data extracted and explored using multivariate statistics. Molecular regions currently being analyzed include the NAD5 and intergenic regions of mtDNA and the internally transcribed spacers (ITS-1 and ITS-2) of rDNA. Preliminary results confirm that Hawaiian *Leptoseris* spp. include morphs not previously known to science.

3C The new age of integrated coral taxonomy
P022

Phylogenetic patterns in the genus *Euphyllia*

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Traditional coral taxonomy almost always relies on the skeletal morphology of the individual. The genus *Euphyllia*, however, is one of the few exceptions to this approach. The genus requires the soft-tissue characteristics in addition to the skeletal morphology to accurately identify its members. The genus expresses phaceloid and flabello-meandroid skeletal growth forms that combine with tentacle characteristics that are either anchor-shaped, club-shaped, and variations of the club shape. However, tentacle and skeletal characteristics are known to change or vary depending on the surrounding environment of the coral. Issues that pertain to morphological plasticity that often interfere with proper identification, might be helped to be resolved by molecular means. Two mitochondrial markers (cox1 and cytb) and a nuclear marker (beta-tubulin) were the regions amplified from the DNA of 30-35 individuals representing 6 species of *Euphyllia* and *Galaxea fascicularis*. Phylogenetic relationships inferred separately from DNA sequences from the three markers showed concordance in placing the genus in the Complex clade of Scleractinia. Furthermore, Maximum Likelihood and Neighbor-joining topologies show two large clusters, supported by 99% and above 88% bootstrap values respectively, between *Euphyllia glabrescens* and the rest of *Euphyllia*. The division agrees with differences in the reproductive behavior between the clusters. Finer details of the topology show high bootstrap values to support the cluster of *E. paraancora* and also to the separate cluster of *E. paradivisa*, which is consistent with the original classification assigned to these species.

3C The new age of integrated coral taxonomy
Friday 13 July, 1415, Sebel Tully

Diversification and phylogenetics in the Caribbean coral genus *Agaricia*

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The biological diversity of coral reefs is renowned, and yet much of that diversity is inadequately quantified and poorly understood. Coral taxonomy has traditionally relied on morphological variation in type skeletons to describe species relationships, but

modern molecular analyses have sometimes produced alternate phylogenies that conflict with traditional systematics. Certain members of the Caribbean coral genus *Agaricia* are focused on here because of their complicated taxonomic history and widely diverse phenotypes. We are using multiple tests to examine species' relationships within *Agaricia*, with the goal of better understanding the evolutionary histories among the phenotypic variants. First, phylogenetic relationships are explored using multiple nuclear and mitochondrial loci. Results thus far show a distinct two clade divergence within *Agaricia* with further molecular classification in progress. Second, morphological comparisons are made by examining fine-scale skeletal variations within and among extant species. Finally, the ecological roles of recognized species are compared, including their preferred growth positions, light habitats, and associations with symbiotic photosynthetic algae. A better understanding of the biological diversity of corals such as agariciids is an invaluable component of conservation research, as well as a significant instrument for comprehending evolutionary processes in marine environments.

3C The new age of integrated coral taxonomy
Friday 13 July, 1215, Sebel Tully

Coral taxonomy at the crossroads: classification, identification, phylogenetics and the quest for informative characters

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The grouping of natural objects into categories and their nomenclature is inherently artificial, and is therefore faced with a number of shortcomings. Scleractinian corals do not escape this paradigm. The development of coral classification did accompany the progress of natural history including palaeontological discoveries, and was almost exclusively based on skeletal morphology and micromorphology characters for some time. The limits of such an approach became evident when the high level of intraspecific phenotypic plasticity grew to be fully realized. This was the time when new investigation tools allowed a turn towards defining more accurate phylogenetic relationships between taxa. A different type of classification scheme with clear evolutionary overtones is progressively being built, co-existing with the older morpho-taxonomic one. In the modern day, taxonomy, however, is expected to meet strikingly different and at times conflicting needs, an expectation only partially met by a holistic approach: the necessity of reliably naming corals is a permanent and often urgent request from those whose task is ultimately to provide means to ensure the conservation of the species - a most worthy endeavour- hence the need to refer to characters that can separate living units quickly and reliably. And if plesiomorphies are still considered to be largely uninformative from an evolutionary perspective, the quest for universal informative characters that could unify the different and at times divergent aspects of coral taxonomy remains unchallenged.

3C The new age of integrated coral taxonomy
P023

Applying the unified species concept to *Pocillopora damicornis* ecomorphs

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According to the 'unified species concept' (USC) proposed by DeQueiroz (2007), species are defined as separately evolving metapopulation lineages, and criteria associated with previously accepted species concepts are used in synergy to assess metapopulation boundaries. Cryptic speciation has been acknowledged for *P. damicornis*, yet the delimitation of the cryptic species is arduous due to extreme morphological and reproductive flexibility reported across the species' global distribution range. Here we apply the USC to delimit cryptic species within the *P. damicornis* complex by combining morphological, genetic, reproductive and symbiont data. Mitochondrial molecular phylogenies (CR, ORF) are congruent with morphological groups indicating at least five genetically distinct lineages. Nuclear markers (HSP70, ITS2) recovered sharp genetic discontinuities among three of these lineages. However, additional information from microsatellite genotyping, gross morphology, symbiotic algae, and reproductive mode and timing indicate intra-specific diversification patterns that are not revealed by the nuclear DNA data, most likely due to introgressive hybridisation. We propose that the lineages identified in *P. damicornis sensu lato* represent different stages along the speciation continuum and hence are difficult to resolve on the basis of a single species concept. The USC therefore appears to fit well in these organisms where cryptic speciation and hybridisation mask classic taxonomic identification, and thus the USC may represent an important conceptual improvement in categorizing ambiguous taxa. This is especially important in *P. damicornis* lineages where the misinterpretation of distinct species as ecomorphs in the past, led to the confusing patterns reported for its biology and ecology.

3C The new age of integrated coral taxonomy
Friday 13 July, 1400, Sebel Tully

DNA Barcoding in Cnidarians: where do we stand? Where do we go?

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Taxonomy of corals and other anthozoans is often problematic and morphological characters are not always providing information reflecting the evolutionary history of the groups studied. Molecular analyses have brought valuable new information to understand the phylogenetic relations between different organisms at various taxonomic levels. While much hope had initially been placed in DNA taxonomy to resolve taxonomic issues and species identification in anthozoans, the slow evolutionary rates observed in this group, rapidly casted doubts on the potential use of DNA barcodes to identify species. In recent years, despite the low interspecific genetic distances for most genetic markers, several studies on different groups reconsidered the DNA barcoding approach and suggested a potential valuable and efficient use of DNA barcoding-inspired methods in species identification. One of the key points of DNA barcoding is the standardisation of the marker used. In cnidarians, the divergence in evolutionary history as well as the, sometime, poor communication between researchers involved in DNA taxonomy led to the development of several parallel DNA based identification systems. Here we will review the different methods used for each group and their resolution power. We will also present the Cnidarian barcoding initiative (CnidBar), an initiative aiming to regroup specialists of the different major cnidarian groups in order to develop a concerted and efficient system, and database based on standardised sets of markers, taking into account the specificity of the different taxa. In an integrative taxonomy approach, the database also includes key morphological or ecological parameters.

3C The new age of integrated coral taxonomy
Friday 13 July, 1445, Sebel Tully

Delimiting species of *Agaricia* using micromorphological and molecular characters

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Over the past 20 years molecular data have replaced morphological data as the primary source of information used to determine evolutionary relationships within the Scleractinia. The utility of molecular markers for assessing both geographic and population scale variability makes them valuable for all levels of taxonomic study. Early molecular studies revealed incongruence between traditional morphologically based taxonomy and the phylogenetic relationships within the Scleractinia. In addition to large-scale taxonomic issues, the lack of molecular markers suitable for species-level studies has been a hindrance to progress; the absence of diversity in mitochondrial DNA makes it more difficult to establish interspecific relationships with such markers, and the nuclear markers that exist rarely work outside of the genus from which they were developed. As more evidence of morphological convergence is gathered and the need for an integrative taxonomic approach is explored, researchers have begun to look for 'new' morphological characters and develop more informative genetic markers. Combined morphological and molecular datasets have the potential to provide a more complete picture of the diversity within a group than does either type of data alone. Here we test the utility of micromorphological characters as well as calcium ATPase, a gene that plays a role in calcium deposition, for distinguishing species in the scleractinian coral genus *Agaricia*.

3C The new age of integrated coral taxonomy
P024

Skeletal structure of scleractinian corals: biological, evolutionary and taxonomic significance

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Traditional geochemical models consider the coral skeleton as a Ca-carbonate precipitate from an extra-cellular, supersaturated fluid, close in composition to seawater and hypothesized to exist between the skeleton and the caliblastic epithelium. Micro(nano)-crystalline 'calcification centers' are supposed to precipitate rapidly during periods of high supersaturation. Less supersaturated conditions result in the formation of elongated crystals ('fibers'), essentially perpendicular to the growing skeletal surface. We show that this classical 'spherulitic model' of scleractinian skeleton growth is a misleading simplification of the coral skeletal growth process: (1) Different scleractinian clades show very different organization of Thickening Deposits. Pocilloporiids or

anthemiphylliids TD are organized as vesicular or lens-shaped units. Flabelliids and acroporids TD are organized into scale-like (shingle) units, sub-parallel to the skeletal surface. Micrabaciids TD exhibitchip-like bundles of extremely thin fibers forming an irregular meshwork within the skeleton, etc. Consistent microstructural patterns are observed for each clade irrespective of ecological (shallow- vs. deep-water) and physiological (zooxanthellate vs. azooxanthellate) conditions. (2) Histological observations of the skeleton-soft-tissue interface have repeatedly shown that the hypothesized space between the calicoblastic epithelium and the skeletal surface does not exist. Instead, a direct physical contact between the calicoblasts and the skeleton is observed, with perfect morphological complementarity between the two surfaces. (3) Different ultra-structural components (TD, RAD, dissepiments, spines) show clear differences in Mg/Ca ratio that can be correlated with the extension rate inferred by dynamic 86Sr labeling, without systematic correlation with Sr/Ca ratios. A biological understanding of microstructural diversity is the new frontier.

3C The new age of integrated coral taxonomy
Friday 13 July, 1130, Sebel Tully

Revision of the recent solitary mussid *Scolymia* in the Indo-Pacific

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Scolymia Haime 1852, which is known as a genus with a solitary form belonging to the family Mussidae, includes two extant Indo-Pacific species *S. australis* (Milne Edwards and Haime 1849) and *S. vitiensis* Brueggemann 1877. However, these two species have been confused with each other in previous taxonomic studies because of the lack of significant differences in morphological characters between them. In the present study using 34 specimens from the Japanese islands, we found that budding positions and conditions of newly formed corallites, pits of alveoli at points of the insertion of new costosepta, and fusions of the fourth to the fifth cycles of septa can be good morphological characters for classifications of these species. These morphological characters reveal that one different species (*Scolymia* sp.) had been included in specimens identified as *S. vitiensis* in previous publications (Wells 1964, pl. XXII, figs. 1-2; Chevalier 1975, pl. XXVII, figs. 3-4). In addition, it also indicates that *S. vitiensis* is a solitary but *S. australis* and *Scolymia* sp. are colonial species. The morphological features of *S. vitiensis* and *Scolymia* sp. are similar to the pectiniids of *Echinophyllia* and *Oxypora* and the mussids of *Lobophyllia* and *Symphyllia*, respectively, and are concordant with their phylogenetic relationships as indicated by Fukami et al. (2004, 2008). On the other hand, *S. australis* may be close phylogenetically to the mussids of *Acanthastrea* according to the morphological characters.

3C The new age of integrated coral taxonomy
P025

Lineage continuity and diversification in *Acropora*: the first 44 million years

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Acropora is the most diversified living reef-building coral genus, and it occurs today in the Indo-Pacific (19 species groups, up to 150 species) and in the Caribbean (one species group, two species). Although its Indo-Pacific diversity has been attributed to mid Miocene Indo-Pacific events alone, this view was challenged by recent interpretations of up to half of the extant species groups of *Acropora* recorded from the Eocene of Europe. To test for a possible source of connectivity between Eocene and present Indo-Pacific *Acropora* taxa, we examined further European fossils from the immediate post-Eocene (i.e. Oligocene to early Miocene), using external skeletal characters to determine species boundaries and species group membership. We found that the samples indicated presence of a diverse *Acropora* fauna of at least 12 species, representing six continuing species group lineages from the Eocene and two first species group occurrences, as well as unplaced species. These findings have significance for dating a molecular clock for *Acropora*, as well as for piecing together the evolutionary and biogeographic pathway to current biodiversity and habitat diversity within the genus.

3C The new age of integrated coral taxonomy
P026

Theme 4. Biophysical processes

4A. Water motion, abiotic & biotic processes on coral reefs

Effects of climatic events on oceanic currents and connectivity

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Climatic anomalies alter ocean circulation patterns and thus connectivity. Comparisons were made between the effect of neutral years and years of moderate El Niño and La Niña events (1993-2007) on the North Equatorial Counter Current (NECC), the South Equatorial Current (SEC), the Coastal Current (CoaC) and the main anticyclonic eddy in the Panama Bight region. Daily topography and wind stress data (AVISO, ECMWF) were used to estimate the speed of surface currents (multi-year, quarterly average) during major spawning months (Sept-Nov). Except for the anticyclonic eddy, the velocity magnitude for all oceanic currents was statistically different among the compared categories; obtaining higher values of speed for neutral>Niño>Niña for the NECC, Niña>neutral>Niño for the SEC; neutral>Niña for the CoaC, and a tendency towards higher values in La Niña years for the anticyclonic eddy. Also, the number of eddies increased in moderate El Niño years. The results suggest that the decreased velocity of the NECC and the potential barriers created by the cyclonic eddies and the anticyclonic eddy near the South American coast could reduce larval dispersal and connectivity between the Central and Eastern Tropical Pacific (ETP). In contrast, during La Niña the SEC could favor teleplanktonic larval transport to the Central Pacific, material that could be exported from the South American coast by the CoaC, aided by the anticyclonic eddy. In conclusion, anomalous climatic events alter the velocity of oceanic currents in the Panama Bight; consequently, these could alter connectivity, having implications for ETP fauna at an evolutionary and ecological level.

4A Water motion, abiotic & biotic processes on coral reefs
P027

How important is flow-delivered organic carbon to coral back reefs?

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While many coral reefs experience high horizontal fluxes of particulate and dissolved organic carbon carried by currents flowing over them, the magnitude of this external input relative to the primary production of the underlying benthic community itself has never been measured simultaneously. Yet quantifying sources of carbon are critical in assessing the independence of reefs from their surrounding waters. We quantified the carbon entering and leaving a control volume 148m long by 1.5-2.5m deep by 1m wide on the shallow back reef of the north shore of Moorea, French Polynesia, and compared it to the simultaneous input of new carbon from carbon-fixation of both the phytoplankton and the benthic community. The wave-driven flow on the transect was unidirectional all year and averaged 9 to 12 cm/s during the study. Greater than 85% of new carbon gained by the control volume per day came from carbon-fixation by the benthic community while <14% originated as flow-delivered particles, including macroalgae, zooplankton, algal fragments, fecal pellets, molts, and microscopic particles, most derived from the fore reef and reef crest, as measured with surface-to-bottom nets and water samples. Gradients in dissolved organic carbon could not be resolved and carbon-fixation by phytoplankton was very low suggesting that benthic processes are most important in controlling carbon dynamics in this system. However, current-delivered organic carbon is clearly an important source of energy to the back reef and likely to be more so at higher flow velocities.

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1645, Sebel Mossman

Impacts of Cyclone Hamish at One Tree Reef

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The southern Great Barrier Reef (GBR), a region that rarely experiences cyclones was impacted by tropical cyclone (TC) Hamish in March 2009. We documented on-reef physical and habitat conditions before, during and after the cyclone at One Tree Reef (OTR) using data from environmental sensor instrumentation and benthic surveys. Over two years of ocean mooring data revealed that OTR experienced large swells (4-8m) of short duration (10-20min) not associated with a cyclone in the area. These swells may have contributed to the physical disturbance of benthic biota and decline in coral cover recorded prior to and after TC Hamish. During the cyclone OTR sustained southeasterly gale force winds (> 61.2km hr-1) for 18.5hrs and swells >6m in height for 4hrs. Benthic surveys of exposed sites documented a 20% drop in coral cover, 30% increase in filamentous algae cover and the presence of dislodged corals and rubble after

the storm. Leeward sites were largely unaffected by the cyclone. Benthic cover did not change in the lagoon sites. Algal cover remained high nearly two years after the cyclone. Laminar corals had not recovered and total coral cover at impacted sites continued to decline. While TC Hamish had a major impact on the reef, changes in benthic cover over several years was due to multiple stressors. This integration of physical and biological data provided a rare opportunity to assess impacts of a major storm and other disturbances, showing the importance of considering multiple stressors (short-lived and sustained) in assessing change to reef habitats.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1230, Sebel Mossman

Waves shape intraspecific variation in a widespread damselfish

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Wave-driven water flow is a major environmental factor limiting the distribution and abundance of marine organisms in shallow aquatic habitats. Distribution patterns of many coral reef fishes have been linked to their swimming morphology and performance across wave energy gradients, suggesting that species are limited to specific habitats according to these features. Yet, some widespread species are routinely found across habitats ranging from sheltered lagoonal fringing reefs to the exposed crests of barrier reefs. How are these species able to thrive in such a broad range of wave environments? I examined the swimming morphology and physiology of the spiny chromis, *Acanthochromis polyacanthus*, a common and widespread damselfish on the Great Barrier Reef in Australia. I studied populations of *A. polyacanthus* around Lizard Island that are distributed across steep wave-energy gradients, but separated by distances of only several hundred meters. I show that morphological and physiological differences among populations are predicted by exposure habitat. Intraspecific morphological and physiological variation in response to a physical environmental stressor has rarely been documented in coral reef fishes. This information is critical to improve our understanding of how coral reef fishes adapt to their local environment.

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1715, Sebel Mossman

Caribbean hybrid *Acropora prolifera* viability restricted to shallow reef zones

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The critically endangered Atlantic scleractinians *Acropora palmata* and *Acropora cervicornis* (Lamarck 1816) produce a fecund hybrid, *Acropora prolifera*, providing a genetic store for the genera as well as limited functional ecological redundancy. This study hypothesized that environmental and genetic factors limit the typical spatial distribution of *A. prolifera* to extreme shallow water reef zones, where *A. palmata* typically occurs, as opposed to deeper reefs (>5m) where *A. cervicornis* is primarily found. At Flay Cay (US Virgin Islands), four visibly healthy *A. prolifera* colonies growing at least 5m apart were fragmented, weighed (buoyant weight), and placed at 2-3m (control), 10m, and 22m depths in different light and current regimes for seven months to assess viability and growth characteristics relative to environmental characters using change in buoyant weight and a photographic time course. Colony maternal inheritance and genotype were also determined. Depth (df=23, p=0.0001) and genet (p=0.0069) both affected fragment growth rates (with no interaction). Control fragments grew faster than both 10m (48%) and 22m fragments (48%, 65% respectively) and three of four genets exhibited different growth rates. Frequency analysis showed depth significantly increased mortality (p=.004), disease incidence (p=.0026), and macroalgal interaction prevalence (p=0.0001). Scanning electron microscopy determined neither depth nor genet caused a difference in axial corallite outer diameter (df=11, p=0.1526, p=0.3447 with no interaction) or a variation in number of axial concentric rings (all-3). The hybrid *A. prolifera* may be restricted to its shallow depth range by environmentally driven post-settlement factors that limit viability at deeper depths.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1130, Sebel Mossman

A numerical model of macro-tidal tropical lagoon: implementation of cross-reef boundary condition

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In the macro-tidal lagoons of the Indian Ocean, coral reefs are temporarily submerged by water at high tide and partially emerged at low tide. This process contributes to lagoon and open sea exchanges, although the reefs are often considered as impervious and the water fluxes assumed to occur only through the passes. Indeed, as observed in Tulear Lagoon, through-passage fluxes control the tidal dynamics. Nevertheless, the cross-reef fluxes can modify the shape of the tidal velocity time series near the reef. They raise quarter diurnal harmonics or create a distortion such as when the

resulting signal loses the property of being a superimposition of several purely sinusoidal components. Furthermore, the residual cross-reef inflow may induce a significant outflow through passages to achieve a balance. We develop a numerical model in order to better understand this hydrodynamic functioning. The cross-reef current is constrained by the tide. It also depends on the waves. The significance of the tidal current on the tidally averaged fluxes varies with the tidal cycle: the input due to breaking waves in windy conditions seems to prevail during neap tide in studied lagoons. Then, the boundary condition on the reef cannot be a classical numerical condition and there is a need to take into account water-level, tidal cycle and waves. Boundary condition optimization is made on a schematic domain to reproduce the cross-reef fluxes.

4A Water motion, abiotic & biotic processes on coral reefs P028

Influence of flow on the symmetry of branching corals

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Differences in exposure to water movement are one of the dominant environmental parameters controlling morphological plasticity in many scleractinian corals. Especially in branching corals, the colony growth form tends to develop a symmetrical shape and the density of branches changes along a range of decreasing water movement. In a recent study it was demonstrated that a uni-directional flow induces asymmetrical colony growth forms in the branching coral *Pocillopora verrucosa*. Under natural conditions *Pocillopora verrucosa* will be exposed to a bi-directional flow and usually colonies will develop which have (in a statistical sense) a radial symmetry. Here we use a simulation approach to investigate the question how uni-directional and bi-directional flow influence the symmetry of the colony. In the simulations an accretive growth model is coupled with an advection diffusion solver. A series of simulated growth forms are compared with a set of Computed Tomography (CT) scans of *Pocillopora verrucosa*. Our results qualitatively agree with the experiments and demonstrate the prominent effect of mono-directional and bi-directional flows on the symmetry of the colony growth form of a branching coral.

4A Water motion, abiotic & biotic processes on coral reefs Wednesday 11 July, 1500, Sebel Mossman

Exploring the physical basis for thermal microclimates on coral reefs

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The history of local environmental conditions on a reef can influence the response of corals to extreme thermal events. Here, we use a three-year record of meteorological conditions, currents, pressure, and water temperature collected on eleven offshore reef platforms in the eastern Red Sea shelf region, near Thuwal, Saudi Arabia, to examine temporal and spatial patterns of temperature variation. From 2008 to 2010 temperature variability on Red Sea reef platforms was dominated by diurnal variability. The daily temperature range on the reefs, at times, exceeded 6°C - as large as the annual range of water temperature on the shelf. Additionally, our observations reveal the proximity of distinct thermal microclimates within the bounds of one reef platform. For example, a coral on the wave-exposed (offshore) side of the reef, which is regularly flushed with water from the shelf, may experience a diurnal water temperature range of 0.5-1.5°C, while colonies of the same species in the interior or wave-protected side of the reef platform, approximately 200 m away, experience a 2-5°C diurnal range. We find that both the temporal and spatial variability in water temperature on the reef platforms is well predicted by a heat budget model that includes the transfer of heat at the air-water interface and the advection of heat by currents flowing over the reef. Additionally, we explore the role that changes in sea level associated with synoptic wind-forcing events play in modifying circulation and the thermal environment on reef platforms.

4A Water motion, abiotic & biotic processes on coral reefs Thursday 12 July, 1215, Sebel Mossman

Cost effective technique for measuring relative water movement

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Water movement has been shown to affect the structure, population and community composition of the marine environment, and as such the ability to accurately and repeatedly monitor and record levels of water movement is important in marine research. We describe a novel, cost effective, repeatable method for measuring relative water movement both spatially and temporally using an 'off the shelf' accelerometer. Water movement recorded by the presented technique was highly correlated ($r = 0.907$, $P < 0.01$) with a recognised commercial device (wave rider buoy). Deployment tests revealed that total wave height show the most significant relationship ($r^2 = 0.83$) with the technique. Use of the technique in a field research situation allowed the detection of small-scale water

movement patterns within the remote Houtman Abrolhos Islands Western Australia, and the quantification of the relative differences in water movement among long-term permanent reef monitoring sites. Overall the technique is a cost effective way of obtaining long-term temporal water movement data at a localised scale or in study areas lacking this information.

4A Water motion, abiotic & biotic processes on coral reefs
P029

Large and small-scale variability of Great Barrier Reef upwelling

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Most reefs in the Great Barrier Reef (GBR) are located on the outer continental shelf where oceanic influences prevail. While intrusive upwelling of Coral Sea thermocline waters onto the GBR shelf has been recognized for 80 years, observational data sets have been largely restricted to small areas and relatively short (<1 to 4 years) time frames. New decadal time series of near-bottom shelf break water temperatures in the central (18°S) and southern (20°S) GBR and re-analysis of historical CTD data indicate that upwelling occurs seasonally over a broad latitudinal range. Shelf-scale intrusion events appear restricted to the open reef matrix of the central GBR. Most events are restricted to the outer shelf. Large shelf-crossing events appear to occur less than once per year. Intensive mixing through the dense reef matrix of the Pompey Reefs (20°S) rapidly disperses upwelled waters and nutrients on the outer shelf, creating a zone of cooler water temperatures and higher pelagic productivity. In the northern GBR, geostrophic factors favour downwelling at the shelf edge. The near-continuous barrier of shelf edge reefs further restricts upwelling to narrow inter-reefal gaps. Nonetheless, upwelling occurs both as short-lived jets and more broad-scale flooding of the outer shelf when the thermocline episodically rises above the shelf edge. Correlations between central GBR upwelling events, wind stress and sea level indicate that oceanographic processes in the Coral Sea exert a strong, largely unresolved, influence on thermocline depths and upwelling activity.

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1545, Sebel Mossman

Heat budget for Florida reefs: reef-scale thermal stress via satellite

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Effective conservation of coral reef ecosystems depends critically on a quantitative understanding of their physical environment, in particular thermal stress. Physical insights into sea temperature variability may help identify reefs less prone to temperature extremes, bleaching, and mortality under varying future conditions. A 20-year record of hourly in situ sea temperature at seven shallow sites in Florida's reef tract (FRT) is analyzed. Variability is dominated by annual, diurnal, and tidal cycles. At sites offshore, near-inertial and 'mesoscale' variability (28h and 3-6 day periods, resp.) is also found, while at the shallowest sites variability in a broad 'weather band' (7-40 days) is observed. A robust inter-annual warming trend is seen at one site. An ocean heat budget is estimated based on sea temperature, atmospheric reanalysis, numerical ocean model outputs, and estimates of heat exchange with the seafloor. The dominant balance is between insolation and latent cooling; benthic heat exchange is also significant at flat, shallow sites. However, at sites on or near sloping topography a small-scale ocean process, the so-called thermal siphon, is invoked to balance the heat budget. The resulting budget models sea temperature variability at periods from 'mesoscale' up to annual (3-365 days), at sites that are diverse in their local topography, and in the thermal forcing and dynamics operating at each. Results are also presented, from applying the heat budget to satellite sea temperature, including additional reef sites where *in situ* data are wholly lacking. Implications for remote sensing of sea temperature variability on coral reefs are discussed.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1000, Sebel Mossman

Effects of water flow and prey behavior on coral feeding

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Scleractinian corals rely on zooplankton prey to meet requirements for both nutrients and carbon. However zooplankton feeding is selective. Small-scale predator prey interactions were evaluated under several flow conditions and using natural prey to determine the interacting effects of water flow and prey behavior on zooplankton capture rates. Avoidance and escape behaviors were determined for many important naturally occurring prey types and related to previously observed selectivity patterns with several coral species. Potential zooplankton contribution to coral nutrient budgets was estimated by modeling zooplankton flux through feeding structures, zooplankton capture probabilities for each prey type, carbon and nitrogen supplied by zooplankton, and observed field coral

growth rates. This research provides a better understanding of mechanisms of prey capture and how these mechanisms affect coral energy and nutrient budgets.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1145, Sebel Mossman

Understanding and parameterizing roughness in circulation models of coral reefs

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Understanding water motion over coral reefs is central to many questions including connectivity of marine populations, fluxes of nutrients, and forces imposed on organisms. Coral reef hydrodynamics are in some ways typical of other shallow coastal flows, but are considerably complicated by the biological substrate that forms a very rough bottom. Coral reef roughness can span several orders of magnitude, is spatially variable, and occurs at scales smaller than can be explicitly resolved in circulation models. Coral exert significant drag on the flow particularly when it occupies a large fraction of the water column. Since drag is usually a primary component of the modeled force balance, it is essential to compute and parameterize drag accurately for models to be predictive. To better understand these issues, we conducted a combined field and modeling study of a shallow coral reef system in Moorea, French Polynesia. A 3D circulation/wave model was constructed using high-resolution bathymetry, and a systematic series of numerical experiments were conducted to determine optimal empirical bottom roughness length-scale (z0) coefficients. Field measurements were analyzed to provide direct estimates of drag coefficients (Cd) using a balance between bottom friction and pressure gradients. These Cd values were converted to z0 values and compared with those from the circulation model. z0 values were also estimated using fits to observed velocity profiles. We will explore the physical mechanisms for the discrepancies between these bottom roughness estimates, and the consequences for modeling circulation on coral reefs.

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1400, Sebel Mossman

Impacts of hydrodynamic shifts on coral condition at Ningaloo Reef

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Climate change is likely to result in sea-level rise and a subsequent reduction in light intensity, as well as changes in ocean current speed and spatial current patterns around coral reefs. Shifts in these parameters are likely to impact the nutrition of corals and subsequently, the health of coral reef communities. To determine the role that local oceanography has on coral health, the condition of two dominant coral morphotypes (branching *Acropora* spp. and plate *Acropora* spp.) was studied over a range of spatial and temporal scales (daily, seasonally, annually) at Ningaloo Reef, Australia. Six stations within six different current regimes were sampled during April 2010, August 2010 and February 2011. At each station, physico-chemical parameters of the water column (light, temperature, current speed, dissolved and particulate nutrients, chlorophyll a, picoplankton, phytoplankton and zooplankton concentrations) were measured in combination with coral health parameters (zooxanthellae density, coral chlorophyll a, protein content, lipid ratios, RNA/DNA ratios, photosynthetic activity). There were significant differences between the two coral morphotypes for the measured coral health parameters. There were also clear differences in the relationships between the different coral health and physio-chemical parameters for the different morphotypes. For example, for branching *Acropora* spp. there was a significant positive relationship between lipid ratios and photosynthetic parameters, while this relationship was not evident for plate *Acropora* spp.. Our results suggest that branching and plate *Acropora* corals have different mechanisms by which they gain energy. We discuss the implications that these results have on our understanding of coral heath.

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1630, Sebel Mossman

DMS production from coral reefs and it's influence on the atmospheric aerosol over Heron Island

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A multidisciplinary ocean-atmosphere study was carried out at Heron Island during May-June 2011 that examined the production of DMS from coral reefs in the region and it's influence on physical and chemical properties of atmospheric aerosol. Our measurements show that DMS production from

corals in this region is extremely high and is thought to significantly affect the radiative climate over reefs. Atmospheric DMS production from corals was examined in control and thermally stressed chamber experiments to monitor how production varied with changes in SST. Production of DMS and other sulphur substances was also examined in a specially designed bubble chamber, which was connected to an aerosol mass spectrometer and an aerosol particle sizer that characterised the chemical composition and physical properties of the aerosol produced from the coral in the bubble chamber. These experimental results were compared with measurements made continuously every 5 minutes, on air masses that travelled over Heron Island, to ascertain whether coral reefs produce atmospheric DMS that could be oxidised to non-sea sulphate aerosols. These aerosols will eventually form cloud condensation nuclei that can significantly affect solar radiation and climate not only over the reefs but also along most of the east coast of Australia. The results of these experiments will be discussed.

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1730, Sebel Mossman

Interaction of hydrodynamics and corallivory control growth of branching *Acropora*

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Coral community shifts are a common recent phenomenon across reefs in the Caribbean and Indo-Pacific, and have been related in time and space to catastrophic natural disturbances, especially storms, crown-of-thorns starfish (COTS) outbreaks, bleaching events, and disease epidemics. Many shifts have been characterized by the loss of branching acroporid corals. Recent work also indicates that chronic, low-level ('press') disturbances also lead to community shifts by influencing the rates of recovery of different coral taxa following catastrophes. Corallivory is a press disturbance that often impacts acroporid corals more than other taxa, thus influencing coral community recovery. We investigated how hydrodynamic conditions (mean current velocity and variance) influence the growth of *Acropora elseyi* with and without partial predation, mainly by butterflyfishes, in Moorea, French Polynesia. Coral growth was greatest under conditions of relatively high current velocities (40-60 cm sec-1) accompanied by moderate levels of velocity variance (a combination of waves and turbulence). But corals performed well in these conditions only when protected from predation: unprotected corals were attacked at the highest rates and grew at the lowest rates. Corallivores had the least impact where velocity variance was greatest, conditions that otherwise generated low rates of coral growth for colonies protected from corallivores. Results from our experiment indicate that abiotic forcing influences coral performance directly through various processes, including material flux, but that coral response, and thus the potential for coral recovery, is highly context dependent, especially where hydrodynamic-habitat interactions influence the abundance of predators and predator attack rates.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1115, Sebel Mossman

Wave-driven flow over a Red Sea platform reef

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Flow across coral reefs determines exchange with the surrounding water and the residence time of water over the reef, which in turn can influence factors that impact coral reef ecosystems such as nutrient flux to the reef and the temperature and alkalinity of the water over the reef. The dynamics of flow across a platform reef in the Red Sea near Thuwal, Saudi Arabia is examined using 18 months of current, pressure, and wave observations. The reef is about 700m long and 200m across. Water depths over the reef varied from 0.7 - 1.6m due to large scale sea level variations on tidal, synoptic, and seasonal time scales. Water flows predominantly across the reef at 5 - 20cm/s during surface wave events typically lasting days. The flow across the reef is driven by a cross-reef pressure gradient, due to elevated sea level on the seaward edge of the reef that is balanced by bottom stress. The setup of sea level on the seaward edge of the reef is 2 - 8cm due to the momentum flux associated with surface gravity wave breaking (wave-radiation stress convergence balancing the setup pressure gradient). Bottom stress is a significant component of the wave setup momentum balance, reducing the sea level setup by 20-30%. Surface wave heights are proportional to water depth after breaking at the reef edge and then decay at a rate consistent with bottom drag on the waves as they propagate across the reef.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1030, Sebel Mossman

Seasonal circulation and temperature variability off Ningaloo Reef, Western Australia

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The circulation and temperature variability on the inner shelf near the North West Cape of Australia off Ningaloo Reef was investigated using field data obtained from two moorings deployed from 2004 to 2009. The results revealed the shelf circulation was,

on average, only weakly influenced by the offshore poleward (southward) Leeuwin Current flow, i.e., monthly-averaged alongshore current velocities were ~0.1 m/s or less. The presence of a consistent summer-time wind-driven equatorward (northward) counter flow on the inner-shelf (referred to in the literature as the Ningaloo Current) was not observed. Instead, the shelf waters were strongly influenced year-round by episodic subtidal current fluctuations (time scale 1-2 weeks) that were driven by local wind forcing. Analysis of the current profiles showed that periods of strong equatorward winds were able to overcome the dominant poleward pressure gradient in the region, leading to upwelling on the inner-shelf. Contrary to prior belief, these events were not limited to summer periods. The forcing provided by these periodic wind events and the associated alongshore flows can explain much of the observed temperature variability (with timescales <1 month) that influences Ningaloo Reef. Implications for the nutrient dynamics and pelagic productivity within Ningaloo's shelf waters will be discussed.

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1415, Sebel Mossman

A cost-effective marine current meter

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Knowledge of the circulation in coastal marine environments is important for understanding many physical and biological processes affecting coral reefs. Typically this is performed using modelling from a limited number of measurements, giving a large-scale estimation of the circulation. However some studies would particularly benefit from spatially dense measurements of current, such as those involving nutrient run-off impacts, localised transport of marine larvae, and upwelling from micro-eddies. To achieve this, deployment of large numbers of instruments is required, which is difficult on a small research budget due to the large cost of commercially available ocean current meters. To resolve this problem we have developed an accurate marine current meter at a much reduced cost. It is robust, easy to deploy, and contains only one moving part. Instrument performance was evaluated by comparing five calibrated instruments against a Nortek Acoustic Doppler Velocimetry (ADV) instrument deployed off Magnetic Island near Townsville, Australia. Results show a current velocity accuracy better than ± 0.05m/s and ±15 degrees compared to the ADV. Analysis of recent applications of the current meter clearly establishes the usefulness of such a device. We identify the coral reef studies where using a large number of our current velocimeters would have greatest impact, and suggest suitable deployment methodologies for them. The availability of a low-cost current meter with high accuracy will greatly help research, monitoring and management of potential impacts on coral reefs and broader coastal marine systems.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1250, Sebel Mossman

Monsoon variability of optical properties in a Malaysian coral-reef ecosystem

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Coral-reef ecosystems around the Malay Peninsula are known to be affected by monsoon seasons. In particular, the North-East monsoon season affecting the East coast has the potential to significantly alter the optical environment which coral-reef ecosystems depend upon. Few studies have considered the implications of the monsoon season with regards to the optical environment. In this study, we (1) clarify the temporal variability of light attenuation, specifically, ultraviolet radiation (UVR; 280-400 nm) and photosynthetically active radiation (PAR; 400-700 nm), and (2) determine the variability of bio-optical factors governing the optical environment in a coral-reef ecosystem. Monthly measurements of light attenuation and bio-optical factors were conducted from June 2010 to June 2011 near Bidong Island, Malaysia (5°36'N, 103°03'E). The annual North-East monsoon appeared from November 2010 to January 2011 during the survey based on wind measurements. The results show distinct temporal differences of the UVR and PAR attenuation coefficients (Kd) and bio-optical factors between the North-East monsoon and non-monsoon seasons. The averages during the North-East monsoon season showed relatively high Kd_{320nm} (1.23±0.44 m^{-1}), low salinity (26.8±0.6 PSU), low temperature (29.4±0.7℃) and high absorbance of aCDOM320nm (1.71±0.04 m^{-1}). The non-monsoon season from June to October and from February to June showed opposite results of low Kd_{320nm} (0.42±0.07 m^{-1}), high salinity (31.2±2.5 PSU), high temperature (30.4±0.9℃) and relatively low aCDOM320nm (0.54±0.30 m^{-1}). The results suggest the optical environment changes significantly due to increased terrestrial and *in situ* derived bio-optical absorbing factors during the North-East monsoon season which could potentially impact coral-reef ecosystem resilience.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1530, Sebel Mossman

The effects of bioturbation by stingrays at Ningaloo Reef, Western Australia

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Stingrays are an important part of the biomass of fishes in shallow, coastal ecosystems, particularly in inter-reefal areas. In these habitats they are thought to be keystone species, responsible for modifying physical and biological habitats through their foraging and predation. Here, we quantify the effects of bioturbation by rays on sand flats of Ningaloo Reef lagoon in Western Australia. At Mangrove Bay we measured 108 pits (length, breadth, depth) on a daily basis for a week. Additionally, an area of 1,000m² of the lagoon at Coral Bay was mapped three times over 18 months, in order to record patterns of ray and pit presence. Over 21 days at Mangrove Bay a total of 1.08m³ of sediment was excavated by rays, equating to a wet weight of 760.8kg, and 2.42% of the total area sampled, or 0.03% of the whole intertidal zone. Based on these calculations we estimate that up to 42% of the soft sediments in our study area would be reworked by stingrays to an average depth of 5.6cm over a year. On average, ray pits persisted in the environment for 4-8 days before being in-filled. An analysis of the change in volume of the pits over time showed high variability in the relationship between pits and years such that only 48% of pits had a negative relationship. Rays play an important ecological role creating sheltered habitats for other taxa in addition to the turnover of sediments and change in the sediment-water interface.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1545, Sebel Mossman

Annual measurement of solar UVB at a reef site using a Polyphenylene Oxide Dosimeter

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Numerous investigations detailed over the last thirty years have highlighted how solar UV (290-400 nm) can have a detrimental effect on coral health. It has also been postulated that coral bleaching is caused by a synergistic process between high water temperatures and increases in UV. As a consequence of its influence upon coral ecosystems, UV radiation must be monitored in underwater locations using an appropriate non-invasive measurement technique, in order to better understand the damage it causes on both a macro and micro scale and provide solutions on how to adequately manage its impact. The high energy UVB waveband (290-320 nm) is believed to have the greatest negative influence on coral stress. This report details the employment of a simple, easily deployable UVB measuring dosimeter system based on polyphenylene oxide (PPO) at a coral reef location near Hervey Bay (25°17 S, 152°52'E) over the interval of one year. Continual deployment of the PPO dosimeters measured a clear inverse correlation between tide level and UVB penetration, with the highest coral UVB exposures measured during the months of winter and spring (coinciding with typically lower tidal conditions during this time). This suggests that the UVB incident on Queensland coral reefs may not be strictly dependent on solar zenith angle (the Sun's position in the sky), which is generally the primary factor in determining the extent of terrestrial UVB exposures. Further, this may mean that photo-damage incident on corals could be exacerbated in traditionally cooler months if current global warming trends continue.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1500, Sebel Mossman

Temperature on Red Sea reefs at two scales: biological consequences

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A series of reefs extend from the coastline to about 20km offshore from Thuwal, Saudi Arabia. The reef flats are typically 100-300m wide, and as breaking waves push water on top of the shallow reef flat from the exposed to the protected side, water may gain or lose heat. On diurnal scales, *in situ* time series indicate that temperature tends to be higher during the day on the protected side of the reef flat than on the offshore wave exposed side. At night, however, patterns reverse, and temperature on the protected side tends to be cooler. Thus, temperature variability is larger on the protected side. Similarly, at scales of 10's of km across the series of reefs offshore from Thuwal, satellite imagery shows that inshore waters tend to be warmer than offshore reef waters during the summer. During the winter, however, inshore waters are cooler than offshore waters. Preliminary analyses of reciprocal transplant experiments on *Stylophora* spp. indicate that corals collected from shallow water (< 2m) throughout the reef flat contained predominantly clade A *Symbiodinium*, but DGGE analysis and cloning of ITS2 revealed additional symbiont heterogeneity, with some colonies on the protected side containing symbionts of clades C and F. These differences may relate to temperature gradients across the reef flat. At larger spatial scales, corals from the inshore reef had higher total lipid content than those from two reefs farther offshore. Finally, we discuss differential mortality patterns in response to a bleaching event.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 0930, Sebel Mossman

Impacts of natural and anthropogenic physical disturbance on coral demographics

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In November 2005 the T/V Sperchios ran aground near Guayanilla, Puerto Rico followed by T/V Margara in April 2006. Data on coral recruitment, survival and community structure were collected annually from 2008-2011 within rubble (Margara) and hardbottom (Sperchios) impacts, restoration structures, and uninjured reference areas of the two grounding sites. Two months after the initial monitoring event, Category 1 Hurricane Omar passed through the area, causing mortality in 25% of coral recruits in the Margara rubble quadrats. In the three subsequent years, only one scleractinian recruit survived within the Margara rubble quadrats, and octocoral recruit survival was low (8-31%). In contrast, recruit survival in hardbottom quadrats at Sperchios and in restored and reference areas at Margara was 40-83%. High coral recruit mortality in the rubble areas may be the result of burial, abrasion, or relocation caused by mobilization of unconsolidated rubble during periodic exposure to high wave energy from winter storms and hurricanes. Five years post-injury, the unconsolidated Margara injury areas had fewer small (< 40cm) octocorals (5.6/m^2) than uninjured reference areas (17.0/m^2). The hardbottom Sperchios injury had significantly more small octocorals (45.2/m^2) than Margara rubble areas. Octocorals in both injuries were primarily fast-growing *Pseudopterogorgia* spp.. Scleractinian demographics did not change significantly within the Margara injury during the study (0.2/m^2, <2.5cm size class), but in the Sperchios injury, scleractinian sizes and density increased. The results suggest that recovery is underway at the hardbottom Sperchios site while recovery at Margara is inhibited by rubble.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1015, Sebel Mossman

The importance of low frequency waves in fringing reef environments

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It is well recognised that hydrodynamic processes occurring within coral reefs are complex, yet are a crucial driver of a broad range of physical and biological processes within these systems. Short period swell wave transformation, wave setup and wave-driven flows over reefs have been the primary focus of most reef hydrodynamic research to date. While low frequency (infragravity) waves have been identified on reefs for some time, their detailed dynamics have received very limited attention. Such low-frequency waves have been shown on sandy coasts to regulate (nearshore) sediment transport and contribute to the morphological development of coastlines, but their analogous importance to reefs (including reef ecology) remains unknown. A three-week field experiment was undertaken at Ningaloo Reef in Western Australia to investigate the importance of low frequency waves across this fringing reef-lagoon system. A synchronised cross-shore instrument array acquired pressure and velocity data, which was analysed to assess the importance of the low frequency waves relative to other sources of water motion (i.e., swell waves and mean currents). The detailed mechanisms responsible for the generation, propagation, and dissipation of these low-frequency waves throughout the reef-lagoon system have been investigated. In this paper the results of this study will be discussed along with the likely importance of low frequency waves on reefs to various processes that are known to rely on water motion (i.e., sediment transport pathways and nutrient dynamics).

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1700, Sebel Mossman

Sea surface temperature (SST) comparation from *in situ* and estimation measurement at Cenderawasih Bay, Papua Indonesia

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The Bird Head Seascape (BHS), Indonesia is home to the world's most diverse coral reefs. Increasing ocean temperatures linked to climate change has led to increased frequency and intensity of bleaching. Bleaching risk is usually assessed using SST from satellite but may not reflect local scale temperature patterns. We compared SST measures from satellite data (NOAA ERMAPPER 30km), with a network of 5 *in situ* temperature loggers (Hobo Pro 2) in Cenderawasih Bay, and TAO Buoys. Few satellite values were available (26 scene) due to high cloud cover. SST data from loggers at 3m and buoys, that were used in this study, were chosen to

correspond to the same days as available satellite images. Satellite temperatures were generally lower than in situ measures by up to 5°C. Comparison of NOAA-loggers and NOAA-buoys showed the same trend. These results can be used for algorithm validation for satellite images. The use of satellite images, large area coverage and accurate measurements will make monitoring more efficient and effective. Keywords: SST, Loggers, Buoy TAO, NOAA, Cenderawasih Bay, Bird Head Seascape

4A Water motion, abiotic & biotic processes on coral reefs P030

Surf's up! Waves modulate foraging and feeding in predatory reef fishes

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Wave action is predicted to increase worldwide due to climate change, with likely repercussions for coral reef fish communities. We urgently need to investigate how waves influence fish predator-prey interactions to improve our capacity for adaptive management of coral reef fish biodiversity. Why? Because predation is fundamental in determining the distribution and abundance of coral reef fishes. Most studies of predator-prey dynamics focus on the interactions between the two players involved. However, physical properties of the environment where these interactions occur, have the potential to drastically alter the dynamics of predation. Currently, we do not know how predator-prey outcomes are influenced by the relative swimming performance of demersal fishes under the highly variable flow regimes they experience on coral reefs. Here, we examined how changing wave conditions (calm, intermediate and rough weather) affect the feeding rate and foraging behaviour in three pairs of benthic carnivorous species (six pectoral-fin swimming fishes from the family Labridae) that differ in their body and fin morphology. We filmed 720 focal individuals for five minute periods at four reef crest sites at Lizard Island on the Great Barrier Reef. Feeding activity varied within and among species according to changing water flow conditions at exposed sites, but not at sheltered sites. I will discuss the implications of these results for our understanding of the mechanisms shaping phenotypic diversity in reef fishes and the spatial management of coral reefs.

4A Water motion, abiotic & biotic processes on coral reefs Thursday 12 July, 0945, Sebel Mossman

Implications of small scale spatial patterns in flow on coral reefs

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Small (1cm - 10m) scale spatial patterns in flow on reefs affect biological processes such as energy expenditure by organisms, nutrient uptake rates, and larval settlement and thus contribute to small-scale patterns in distributions of organisms on reefs. Additionally, flow patterns at these scales determine drag exerted on water as it passes over reefs, and rates of dispersion and mixing, which must be parameterized in reef circulation models. Most field and modeling studies of reef circulation focus on flow patterns at >100m scales and hence there is little documentation of small scale spatial variability of flow on reefs. We will describe high resolution computer simulations and field measurements from a reef flat in Moorea, French Polynesia, that provide insight into spatial variability of flow on reefs at scales ranging from a single branch (1-cm) to a patch of coral colonies (10-m). Our results illustrate that currents on reefs can be highly variable at these scales and that small-scale variability often exceeds trends due to larger scale gradients in flow. Similarly, turbulent mixing is extremely patchy and maximized in high shear regions at the edges of colony wakes. Spatial flow patterns can also vary significantly in time due to varying colony-scale Reynolds numbers. Hence care must be taken in interpreting point velocity measurements on reefs and output of reef circulation models. We will conclude by discussing the relationship between colony-scale bottom topography, sub-grid-scale flow variability, and spatially averaged drag exerted on flow over reefs.

4A Water motion, abiotic & biotic processes on coral reefs Wednesday 11 July, 1530, Sebel Mossman

Parameters that influence coral biodiversity and accretion on high-latitude East African reefs

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Surveys have revealed gradients in East African scleractinian and alcyonacean distribution and these are reviewed. While reefs in the south are unexpectedly rich in biodiversity, they are non-accretive and the reasons for this are elaborated. Global models have suggested that light, temperature and aragonite saturation, particularly the last, should be limiting on the high-latitude South African reefs. However, summer and winter determinations of aragonite saturation in the water column over the reefs respectively yielded values of 4.40 and 4.33, above the minimum requirements of Scleractinia. Other parameters are thus responsible for low accretion on the reefs and these constitute high turbulence, sediment resuspension rather than cementation, and high bio-erosion and competition between Scleractinia and Alcyonacea. Results of studies on these parameters will be presented showing how they favour carbonate removal rather than carbonate deposition on these high-latitude reefs.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1515, Sebel Mossman

Water flow, nutrition, and limits to growth in reef corals

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Scleractinian corals use a wide range of resources to add tissue and calcify in habitats with scarce and potentially limiting resources. Coral species display a breadth of colony and polyp morphologies related to resource capture, water flow, and irradiance. On shallow reefs, zooxanthellae produce more than enough photosynthate to meet metabolic demands, yet nutrients needed for tissue growth can still be limiting. In low light reef habitats, photosynthesis does not meet energetic needs, and either zooplankton or other particulate material can be important sources of both nutrients and energy, and dissolved nutrient uptake can also be important. Experiments have shown that plankton capture rates can control calcification and tissue growth in several coral species; this effect can be of greater magnitude than that of other known controls, such as available bicarbonate concentrations, calcium saturation state, and water flow. Branch size and spacing, polyp size, and tentacle morphology, all affect light and particle capture, and also affect the local flow environment in coral aggregations. Examining interspecific differences in morphology and differential utilization of nutritional resources can help explain patterns of coral diversity, zonation, and abundance on reefs. New and published information on water flow, particle delivery, and flow effects on physiology and calcification are used in models dealing with trade-offs among physiological processes affecting coral energetics and growth. Such information can be useful in interpreting changes in growth rate and survivorship, with predicted changes in habitat quality, temperature, and seawater chemistry over the coming decades.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1200, Sebel Mossman

Dimethylsulfide and the coral reef ecosystem

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Dimethylsulfide (DMS), which is mainly derived from dimethylsulfoniopropionate (DMSP) produced by oceanic phytoplankton, is the major biogenic source of atmospheric sulfur. A recent estimate is that 28 Tg of DMS is released from the oceans to the atmosphere annually, where it is oxidised and can contribute to new nanoparticle formation leading to cloud condensation nuclei. The Earths radiation budget is affected by the number of these small sulfur particles because they can directly scatter radiation back into space and also indirectly affect the microphysical properties of cloud albedo to cool the planet. DMS and DMSP are also produced by endosymbiont cells in reef-building corals. Free DMS plus bound DMS released from DMSP, was measured in healthy nubbins of *Acropora valida* and *Acropora pulchra*, and on average was approximately 4 µmol/cm^2 surface area. In zooxanthellae extracted from these coral species it was up to 15 pmol/cell, which is higher than is typically found in phytoplankton cells. Although coral reefs occupy <1% of global oceans, the potential source strength of DMS from these areas is significant in comparison to other oceanic areas. Disturbance to coral reefs may potentially affect sea-to-air emissions of DMS leading to possible climatic impact. In the marine environment, disturbance may also lead to alterations in trophic interactions, phase shifts and loss of biodiversity because DMS may have a role as a food-chain infochemical. These issues will be presented based on information gained from the Great Barrier Reef.

4A Water motion, abiotic & biotic processes on coral reefs
Thursday 12 July, 1245, Sebel Mossman

Q-IMOS monitoring of currents along the outer Great Barrier Reef

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The Queensland node of the Australia's Integrated Marine Observing System (IMOS) was established in 2007 to provide robust and sustained ocean observations. Q-IMOS is an Australian Government initiative established under the National Collaborative Research Infrastructure Strategy and the Super Science Initiative, and is supported by Queensland State Government. It provides real time and delayed mode observations from weather stations, oceanographic moorings, underway ship observations, gliders, ocean surface radar, satellite image reception and reef based sensor networks. All data is made freely and openly available through the IMOS ocean data portal that is accessible from www.imos.org.au. This poster focuses on the array of in-line moorings that have been deployed along the outer Great Barrier Reef in order to monitor the Western Boundary currents of the Coral Sea. The four mooring pairs consist of a continental slope mooring, nominally in 200-300m of water and one on the outer continental shelf within the GBR matrix in depths of 30 to 70m. The array is designed to detect any changes in circulation, temperature response, mixed layer depth and ocean-shelf interactions. Output from a new near-real time 4km resolution three-dimensional hydrodynamic model covering the entire GBR and extending eastwards into the Coral Sea Territories, is being used to help

understand and interpret the oceanographic observations and vice versa.

4A Water motion, abiotic & biotic processes on coral reefs P031

Quantifying wave stress on coral reefs

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Coral reef ecosystems are subject to numerous and often stressful environmental forcing that affects the health and overall resilience of reef communities. Studies of stress on coral reefs have historically focused on sea surface temperature, in response to coral bleaching events, and more recently on ocean carbonate chemistry, in response to reductions in pH. Wave-stress events can be highly influential to the distribution, growth and diversity of reef organisms, from disturbances, such as overturning, breakage and dislodgment of corals and benthic organisms, to providing nutrients, aeration and larval distribution. Extreme events are a natural part of a coral reef environment, comparable to natural wildfires clearing a forest for new growth; however, an increase in these events could be detrimental to an already weakened ecosystem. We present a novel approach to quantifying wave stress on coral reefs, with a focus on island-scale, ecologically relevant wave-stress events and their effects on coral reef communities. Using a Points Above Threshold method on a 14-year time series of wave model output, an ecologically relevant threshold for wave energy is established, and a metric of wave-stress impact is developed that incorporates both magnitude and duration of extreme events. Once established, these metrics can be used to monitor long-term changes in wave energies and effects of extreme wave events. This work will assist coastal zone managers and island communities to prepare and develop policies that help mitigate coral reef damage associated with extreme wave-stress events.

4A Water motion, abiotic & biotic processes on coral reefs Wednesday 11 July, 1515, Sebel Mossman

DOC dynamics analysis with a new biogeochemical reef ecosystem model

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We have developed a 3-D biogeochemical ecosystem model for fringing reefs, which incorporates a microbial and classical grazing food web and is coupled with a 3-D ocean current model, the Princeton Ocean Model, with some modifications. We have applied the model system to a typical fringing reef in the east coast of Ishigaki Island, Okinawa, Japan for the period from August to September 2009. The computer simulation results were compared with field measurement data for the hydrodynamic and chemical parameters to examine model validity. The simulated water surface elevation and velocity fluctuations agreed well with the observed data. The simulation could also well reproduce the observed fluctuation patterns of dissolved organic carbon (DOC) in diel and tidal cycle time scales. The highlight of the present work is that the variation in DOC concentration in the water column of the reef was found to be sensitive to the release of coral-derived DOC and became less reproducible when the release rate of coral-derived DOC was controlled to be scarce. The result emphasizes the role of coral mucus as a source of reef DOC and is a quantitative demonstration of the importance of coral-derived DOC as a carbon source in the reef ecosystem.

4A Water motion, abiotic & biotic processes on coral reefs Wednesday 11 July, 1430, Sebel Mossman

Modelling calcification in coral reefs using a coupled physical-biogeochemical approach

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The declining growth of coral reefs due to increased thermal stress and ocean acidification has become a wide-spread concern. Corals and other reef calcifiers build their skeleton from calcium carbonate via calcification, a process which causes a reduction in the total alkalinity (TA) of ambient seawater. Consequently, observed declines in seawater alkalinity can be used in conjunction with estimates of water residence times to calculate calcification rates at the community and system scales. While crude versions of such calculations have been performed many times in reef systems, the major challenge at present is to accurately resolve residence time, a variable which is strongly dependent on the hydrodynamic processes driving circulation in real coral reef systems. In this study, we used a coupled physical-biogeochemical numerical model to simulate both the residence time and TA of the Coral Bay reef-lagoon system located in the heart of the Ningaloo Reef Tract. While residence time was calculated entirely from the hydrodynamic model, TA was modelled as a non-conservative tracer based on light-calcification relationships derived from a control volume experiment conducted on the adjacent reef flat. Results showed that the coupled model was capable of reproducing the observed spatial

variability of TA and that both TA and residence time varied strongly as a function of wave forcing. This new modelling approach provides us with a means of accurately estimating calcification rates for entire reef systems based on observed gradients in TA and thus provides a new and powerful tool for coral reef monitoring.

4A Water motion, abiotic & biotic processes on coral reefs
Wednesday 11 July, 1445, Sebel Mossman

4B Chemical ecology of coral reef ecosystems

$\delta^{13}C$ and $\delta^{15}N$ of organic matter sources in New Caledonia

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Particulate organic matter (POM), surface sediment and major species of macrophytes were sampled in several habitats. POM presented lower $\delta^{13}C$ and higher $\delta^{15}N$ values than surface sediments (-22.53 ± 0.61 and 5.18 ± 0.20 versus -18.42 ± 3.13 and 3.85 ± 0.47, respectively). Mangrove POM was $\delta^{13}C$-depleted (-25.44 ± 1.54) when compared to coral reefs (-22.84 ± 1.56), but differences in $\delta^{15}N$ values between habitats were not significant. The $\delta^{13}C$ values in surface sediments varied from -23.03 ± 1.58 in mangroves to -14.51 ± 0.44 on fringing reefs. $\delta^{13}C$ and $\delta^{15}N$ values of macrophytes strongly varied. Mangrove trees were characterised by lower $\delta^{13}C$ and higher $\delta^{15}N$ values than algae and seagrass. Our results discriminated $\delta^{13}C$ and/or $\delta^{15}N$ values between the sources of organic matter. It is thus possible to separate the source(s) of organic matter used by species in food webs, and assess the main pathways of energy fluxes within the coral reefs of New Caledonia.

4B Chemical ecology of coral reef ecosystems
P032

Trace element analyses in edible seaweeds from the Kenyan coast

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Seaweeds are widely used as human food, animal feed, fertilizers, salt extractors and pharmaceuticals in Orient countries, particularly in China, the Korean Peninsula and Japan. The seaweed industry in Kenya has great economic potential due to the world's growing demand for carrageenan. It is imperative to mention that seaweeds and corals reefs form an integral part of marine ecosystem being fisheries of enormous economic importance. Taking into account Kenya's potential to produce edible seaweed, especially the Eucheumoids and Gracilaroids used for hydrocolloid production in food industries, the present study was done to examine its trace element levels in seaweeds collected along the Kenyan coast. This study sought to establish the total and bioavailability concentrations of trace elements in the edible seaweed using X-Ray Florescence technique. The concentrations of calcium, chromium, manganese, iron, copper, zinc and lead in seaweeds obtained from various sites were investigated and the results will be presented. The implication of the bioavailability studies was evaluated and the results will be presented. Overall the total concentrations of metals examined were within the range recommended in dietary intakes.

4B Chemical ecology of coral reef ecosystems
P033

Insights into the chemical ecology of fish aggregations over reefs

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Coral reefs and the processes they support create a chemical landscape through which fish navigate their entire lives. We know that chemoreception can be integral to how larval fish find reef habitat and adult fish find home. Yet, we are far from understanding how important chemoreception is to adult fish actively searching out foraging opportunities and other productive habitats in the pelagic environment. We know from previous work that planktivorous fish are attracted to dimethylsulfonioprionate (DMSP), an important metabolite produced by marine algae. To further investigate the possible suite of chemical cues employed by pelagic fishes, we sampled seawater from the middle of multi-species fish foraging aggregations and control sites along the barrier reef of Belize. We preserved samples for DMS and DMSP quantification and filtered 5 L of both aggregation and control seawater over C18. We then conducted bioassays on wild-caught *Abudefduf saxatilis* using previously frozen, filtered whole seawater samples and C18 extracts from aggregation and control sites. Here we show that chemical cues collected from in the middle of multi-species fish foraging aggregations are attractive to adult reef fish and provide insights into the analytical process of discovering the nature of these compounds. These results provide the first evidence that chemical signatures collected from fish aggregations could be used as attractive cues for pelagic fish as they navigate the reefscape.

4B Chemical ecology of coral reef ecosystems
Wednesday 11 July, 0930, Sebel Mossman

Patterns in Australian marine bioactivity: are coral reefs bioactivity hot spots?

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Twenty-five years of Australian marine biodiscovery research with the AIMS Bioresources Library has explored biodiversity collected from the breadth of Australia's ocean territory including latitudinally and longitudinally diverse coral reefs. The resulting, immense database, integrates biodiversity with bioactivity data, and this was mined to retrospectively assess biogeographic, taxonomic and phylogenetic patterns in cytotoxic, anti-infective, and CNS-protective bioactivity. While the bioassays used were originally chosen to be indicative of pharmaceutically relevant bioactivity, the results have been cautiously interpreted with respect to the ecological significance of secondary metabolism, in the context of ecological parallels between the bioassay system and marine chemical ecology, and the issue of scale. In general, Metazoan Phyla along the Deuterostome phylogenetic pathway (e.g. Bryozoa, Echonodermata and leading to Chordata) and their ancestors (e.g. Porifera, Cnidaria) had higher percentages of highly active samples in the assays examined. While taxonomy and phylogeny helped explain observed trends, the results did not support the presence of any overall biogeographic bioactivity hot spots. Further analysis and discussion explored the hypothesis that after phylogeny and therefore the metabolic machinery available to an organism, habitat diversity and ecological circumstance are the major drivers in the activation of this machinery and actual bioactive secondary metabolism. This presentation is dedicated to the memory of Dr Peter Murphy, pioneer of modern marine biodiscovery, and founder of the AIMS Bioresources Library.

4B Chemical ecology of coral reef ecosystems
Wednesday 11 July, 1015, Sebel Mossman

Sex steroids induce corals to spawn

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During annual coral spawning events, it is crucial for conspecifics to spawn synchronously in order to maximize fertilization. A variety of different cues have been suggested to synchronize coral gamete release. Sex steroids peak during spawning and have been proposed as a pheromone to ensure spawning precision. This study uses compounds isolated during previous spawning events and synthetic steroids to test spawning induction. During the first year, ripe *Montastraea franksi* fragments were collected and placed in buckets prior to sunset. After the corals spawned, the seawater was passed over 10g C-18 columns. Compounds were eluted from C-18 using three solvents 1:1 H_2O/MeOH, MeOH, EtOAc. The following year ripe *M. franksi* fragments were collected and each coral was split in half (200-400 cm^2). Prior to sunset, corals were placed in buckets with 2 litres of seawater. When setting (i.e., gamete bundle becomes visible in the mouth of the polyp) was observed, a control or a treatment was applied to each fragment. The treatments included the three fractions or a sex steroid cocktail of testosterone, progesterone, estradiol and estradiol glucuronide applied at natural concentrations found during coral spawning. The MeOH fraction and sex steroid cocktail induced spawning earlier than controls. These preliminary findings suggest that sex steroids are likely the pheromone that is involved in spawning synchrony. Identifying the specific sex steroid used for spawning synchrony and the minimum concentration that neighboring conspecifics can detect will be important questions to answer in light of the decline of corals worldwide.

4B Chemical ecology of coral reef ecosystems
Wednesday 11 July, 1000, Sebel Mossman

Phosphorus species characterization by ^{31}P-NMR in the coral *Stylophora pistillata*

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Despite the key importance of phosphorus for corals, little is still known about its metabolism within the symbiosis. To determine the chemical species in which phosphorus occurs in the two partners of the symbiosis, we used nuclear magnetic resonance spectroscopy (^{31}P-NMR), an advanced technique that has already been proven an excellent tool to study phosphorus metabolism in various marine organisms. Phosphorus spectra of animal host and freshly isolated zooxanthellae (FIZ) cells from the scleractinian coral *Stylophora pistillata* were compared, with a particular focus on the effect of the nutritional status of the coral. To highlight a possible incidence of the symbiotic state for the zooxanthellae, we also performed ^{31}P-NMR spectroscopy on cultured zooxanthellae (CZ). Finally, we tested the impact of organic and inorganic phosphorus enrichments of the CZ. Beyond the difficulties to identify the very species present, we have determined the families of compounds in which phosphorus occurs within the symbiosis. Very different NMR profiles were found between zooxanthellae and animal cells, but also between FIZ and CZ. Zooxanthellae exhibited a lower chemical diversity than the animal host, with a large variety of phosphonates in host cells that were rather absent in the symbionts. Polyphosphates, that were expected to be a privileged form of phosphorus storage in the zooxanthellae, were totally missing. Phosphate enrichment led to an increase of intracellular phosphate in CZ, contrarily to organic phosphorus enrichment. Our results evidence the interesting possibilities of ^{31}P-NMR

spectroscopy as a tool for the study of phosphorus metabolism in symbiotic corals.

4B Chemical ecology of coral reef ecosystems
Wednesday 11 July, 1030, Sebel Mossman

Feeding preferences of *Diadema antillarum* in the U.S. Virgin Islands

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The die-off of the long-spined sea urchin *Diadema antillarum* in Caribbean waters in the 1980s coincided with a dramatic increase in macroalgal biomass on coral reefs. An increase in abundance of this keystone herbivore should dramatically decrease macroalgae on Caribbean reefs, therefore scientists and resource managers are interested in its recovery. We investigated the feeding preferences of this herbivore for different macroalgae and cyanobacteria that are common on reefs of the U.S. Virgin Islands. Many of these coral reef algae are chemically rich, and some are known to be chemically defended against generalist grazers. However, the feeding behavior of this important herbivore and its avoidance of chemically-rich macroalgae and cyanobacteria have not been thoroughly investigated. *Diadema antillarum* was more selective than expected in its food choices and tended to avoid some common macroalgae and cyanobacteria. We found that extracts of the brown macroalgae *Dictyota menstrualis* and *D. pulchella* and the cyanobacterium *Dichtothrix utahensis* deterred feeding by *D. antillarum*. These algae are common on shallow reefs of the U.S. Virgin Islands where sea urchins are becoming more abundant, but may not be readily eaten by this herbivore.

4B Chemical ecology of coral reef ecosystems
P035

Social learning and acquired recognition in a marine fish

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Predation is known to influence the distribution of behavioural traits among prey individuals, populations and communities in both evolutionary and ecological time scales. Prey have evolved mechanisms of rapidly learning the identity of predators. Chemical cues are often used by prey to assess predation risk, especially in aquatic systems where visual cues are unreliable. Social learning is a method of threat assessment common among a variety of freshwater fish taxa, which incorporates chemosensory information. Learning predator identities through social learning is beneficial to naive individuals as it eliminates the need for direct interaction with a potential threat. Although social learning is widespread throughout the animal kingdom no research on the use of this mechanism exists for marine species. In this study we examined the role of social learning in predator recognition for a tropical damselfish, *Acanthochromis polyacanthus*. This species was found to not only possess and respond to conspecific chemical alarm cues, but naive individuals were able to learn a predator's identity from experienced individuals; the process of social learning. Fish that learned to associate risk with the olfactory cue of a predator responded with the same intensity as conspecifics that were exposed to a chemical alarm cue from a conspecific skin extract.

4B Chemical ecology of coral reef ecosystems
Wednesday 11 July, 0945, Sebel Mossman

Algal chemical ecology: from compounds to communities

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Macroalgae and benthic cyanobacteria are becoming increasingly abundant on reefs, and many of these dominant algae produce diverse secondary metabolites. Abundant brown and green macroalgae and nuisance blooms of cyanobacteria occur regularly throughout Florida and on the Belizean barrier reef. Crude extracts from some macroalgae and cyanobacteria deter feeding by natural assemblages of fishes and the sea urchin *Diadema antillarum*. In addition, macroalgal and cyanobacterial secondary metabolites may serve multiple ecological functions, including inhibition of microorganisms and competition for space. The role of allelopathy (chemical inhibition) in mediating the interactions between chemically rich species of algae and cyanobacteria and different life history stages of corals was tested. Extracts and isolated compounds from *Dictyota* spp., *Lyngbya* spp. and other cyanobacteria negatively influenced the settlement and metamorphosis of coral larvae. On reefs experiencing increased abundance of chemically defended macroalgae and benthic cyanobacteria, the restocking of adult coral populations may be slowed due to recruitment inhibition caused by algal natural products. Natural products protect some algae from herbivory (allowing increased space occupation) and reduce coral recruitment, both of which may perpetuate a 'phase shift' from coral to algal dominated communities.

4B Chemical ecology of coral reef ecosystems
Wednesday 11 July, 1040, Sebel Mossman

Chemical proxies of floods and upwelling in otoliths and corals

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Chemical records in biogenic carbonates such as fish otoliths and coral skeletons can be effective recorders of fluctuations in ambient environmental parameters. While coral aragonite is frequently analyzed to reconstruct historic variation in reef environments at a fixed locale, otoliths of stationary fish species also have the potential to be powerful tools for reconstructing variation in ecologically important parameters, such as temperature, salinity, and nutrient availability. Together, chemical analyses of coral skeletons and fish otoliths can potentially reveal important information about the frequency and intensity of pulsed environmental events and their species specific ecological effects. We present results from an on-going project to monitor water chemistry and associated variability in Ba:Ca recorded in otoliths of a resident pomacentrid fish, as well as from *Porites* coral at inshore and offshore locations on the Great Barrier Reef. Inshore environments experience strong pulses of freshwater correlated with increases in Ba:Ca in sea water and also carbonate Ba:Ca ratios. Ba:Ca ratios in both corals and otoliths therefore act as an effective proxy for natural and anthropogenic influences on near shore habitats. Also, offshore reefs are exposed to regular upwelling events. Deep waters (> 150m) were richest in Ba:Ca and temporal depositional patterns in both fishes and coral were observed. Otolith Ba:Ca has the potential to complement records in coral skeletons and reveal ecological responses of fish populations to high-frequency fluctuations in oceanographic parameters.

4B Chemical ecology of coral reef ecosystems
Wednesday 11 July, 1035, Sebel Mossman

Nitrogen isotope of coral skeletons as a proxy for marine nitrate sources in coral reefs

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Coral skeleton could be a high-resolution recorder of past nutrient dynamics in tropical and subtropical oceans with decades to millennia time scales. The nitrogen isotopes of organic nitrogen in coral skeletons could be used to record nitrogenous nutrient origins in coral reefs. In this presentation, we introduce the potential of coral nitrogen isotope as a proxy for marine nitrate. For the proxy development, we demonstrated the intra- and inter-reef variations of coral nitrogen isotope in the western Pacific. The zonal distribution of coral nitrogen isotopes found inside a coral reef corresponded with nitrogen isotopes of seawater nitrate. The extended analysis of coral nitrogen isotopes among various coral reefs also shows a latitudinal gradient from tropical to temperate in the western Pacific. This result suggested that nitrogen sources for reef corals was mainly nitrate in reef water, and coral skeleton recorded the nitrogen isotopes of nitrate. Time series of coral nitrogen isotopes provide the potential to reconstruct seasonal to inter-annual variations of nitrate sources to coral reefs, such as land-derived nitrogen, nitrogen fixation, and upwelled nitrate. We also introduce application examples of a nitrogen isotope proxy to corals.

4B Chemical ecology of coral reef ecosystems
P036

4C Coral reef response to multiple stresses: organisms to ecosystems

Declining growth of corals at Lord Howe Island

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Climate change poses a significant risk to the future status of coral reefs, whereby increasing ocean temperature may cause declines in growth and survivorship of reef-building corals. At high latitude locations, however, increases in ocean temperatures may actually have a positive effect on coral growth. The important question is whether ocean acidification is offsetting any positive effect of increasing temperature, such that these corals are growing slower due to reduced capacity for carbonate accretion. The purpose of this study was to measure the linear extension rate of branching corals, such as *Acropora*, *Isopora*, *Pocillopora*, *Porites*, *Seriatopora* and *Stylophora*, at Lord Howe Island and compare the linear extension to data collected in the mid 1990s. Growth was measured based on linear extension following alizarin red staining as well as tagging of replicate branches on a number of colonies. During the first sampling period (November to March), it appears that *Pocillopora* is growing more slowly compared to comparative estimates in the 1980's. Conversely, *Acropora* has shown no change in density and may have increased growth. Ongoing sampling is required to measure annual linear extension rates, which will provide much robust measures of current growth rates for all coral taxa. If branching corals are growing more slowly at Lord Howe Island, it may be that changes in ocean chemistry (specifically, aragonite saturation) are already impacting corals at the latitudinal extremes of their geographic ranges.

4C Coral reef response to multiple stresses: organisms to ecosystems
Thursday 12 July, 1715, Sebel Mossman

Environmental factors affect soft coral-derived organic matter fluxes

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Organic matter (OM) release by benthic organisms can importantly control coral reef ecosystem functioning, but may be affected by variations in inorganic nutrient and light availability. While OM fluxes have been studied for several dominant reef taxa, no information is available on soft corals, a highly abundant group in many tropical reef habitats. Thus, the present study investigates OM fluxes by the common soft coral genus *Xenia* at two light availabilities, two different ammonium (N) and phosphate (P) concentrations and a respective combined inorganic nutrient enrichment (NP). Subsequently, the effect of OM fluxes on planktonic microbial activity was assessed. Findings revealed lower OM flux rates (ca. 10-fold) for Xenia compared to other reef coral taxa. OM fluxes were net negative (-0.32 ± 0.16 mg POC, -4.82 ± 2.13 mg DOC and -0.05 ± 0.02 mg PN m^{-2} coral surface area h^{-1}) and net positive (0.24 ± 0.14 mg POC, 1.04 ± 1.15 mg DOC, 0.03 ± 0.02 mg PN m^{-2} coral surface area h^{-1}) at high and low light conditions, respectively. While DOC uptake significantly increased in response to N and NP addition, POC flux was not affected by inorganic nutrient availability. P enrichment under high light significantly stimulated PN release leading to 9-fold elevated microbial O_2 consumption rates compared to low nutrient condition. This study provides first information on soft coral-derived OM fluxes under variable environmental conditions with implications for potential changes in processes paramount to reef ecosystem functioning after phase-shifts from hard to soft coral dominance.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1145, Sebel Mossman

LAIW as a driving factor for coral reef resistance?

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Variations between the response of coral reefs to fluctuating thermal regimes have been observed, with some corals exhibiting more resistance to temperature variations than others. The temperature stress response of *Porites lutea* from exposed and sheltered reefs to LAIW (Large Amplitude Internal Waves) was investigated by conducting three long term aquaria manipulation experiments using different stress conditions: A) Water temperatures fluctuations (LAIW simulation) from 24°C - 29°C, B) Induced bleaching conditions with 31°C, C) Temperature fluctuations + bleaching conditions from 24°C - 31°C. Thermal-tolerance of the corals was measured by analyses of the dark adapted maximum quantum yield, zooxanthellae densities in the coral host tissue, chlorophyll a concentrations, protein content and genetic analysis of the associated ITS-2 symbiont type. *Porites lutea* from LAIW exposed sides showed a higher thermal resistance and tolerance to bleaching conditions compared to east fragments, reflected during the experiments in higher MQY values, zooxanthellae densities, chlorophyll a content, protein content and lower mortality rates. The only ITS-2 symbiont type (C15) found in the *Porites* colonies points to the acclimatization potential of this zooxanthella type, but highlights also the role of other resistance factors and the role of the host in determining the corals bleaching response. This study clearly shows the influence of fluctuating thermal regimes (as LAIW influence) on the thermal stress response of coral reefs as a mechanism and driving factor for differences in coral reef temperature tolerance.

4C Coral reef response to multiple stresses: organisms to ecosystems
P037

Impacts of coral growth anomaly on organismal and population viability

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Montipora capitata corals at Wai'pae tidepools, southeast Hawai'i Island, display much higher prevalence levels of growth anomaly (GA) compared to other surveyed sites throughout the Hawaiian Archipelago. Reduced water flow in this tide pool environment is likely to impede removal of terrigenous pathogens or stressors. Micromorphological analysis suggests the GA pathogenesis progresses from diagnostically distinct Type A to B, with Type B exhibiting more degenerative morphological signs of this disease. Exhaustive surveys of disease severity produced epizootiological data that determined colony size, horizontal colony orientation, and lack of water circulation to be cofactors of GA cover. Histopathological analysis of this disease revealed that the GA tissue undergoes changes in cellular morphology which compromise biological functions such as defense, energy acquisition, digestion, and reproduction: demonstrated by significant ($p<0.05$) reductions in densities of nematocytes (28.8-46.0%), symbiotic dinoflagellates (38.88-67.5%), mesenterial filaments (11.2-29.0%), and gonads (66.1-93.7%), respectively. Photophysiological analysis showed that the endosymbionts within GA tissue exhibit reduced ($p<0.01$) photochemical efficiency, expressed in Fv/Fm and ΔF/Fm', compared to healthy tissue. Combining the histopathological effects of GA with epizootiological data allowed quantification of the threat of this disease to organismal and population viability. For example, collating histological data on gonad density with GA severity in the same population, showed that GA reduces the fecundity of individual *M. capitata* colonies by 0.7-49.6% and the overall population fecundity at Wai'pae by 2.41±0.29%. Performing this type of comprehensive assessment is critical for grasping the magnitude of threat posed

by coral diseases at the organismal and population levels.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1200, Sebel Mossman

New insights on coral bleaching mechanisms

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Bleaching is defined as the loss of coral pigmentation due to a decrease in the number of symbiotic zooxanthellae in the coral and/or the degradation of photosynthetic pigments of zooxanthellae when corals are under stressful high seawater temperatures. UV radiations, high illumination, and low water temperature, are also recognized as bleaching triggers. Recently it was hypothesized that death of corals after bleaching events is facilitated by opportunistic infectious pathogens whose virulence is enhanced by increased temperatures. We designed a series of experiments in which branches of the coral *Montipora digitata* were kept under normal (28°C) and stressful (32 °C)) temperatures in aquaria with running natural seawater. After 4 days, half of the corals were inoculated with monocultures of 5 different bacteria strains to compare bleaching process under solely high temperature or that in combination with possible pathogens. Metabolic changes in corals and their symbionts were evaluated throughout primary production, calcification and respiration rates among others. Zooxanthellae density and their photosynthetic status were also registered through the experiment. Under the combined effects of abiotic and biotic stressors, primary production and calcification were reduced respectively by 66% and 101%, compared to 28% and 77% under solely temperature stress. Moreover zooxanthellae density reduced to 70%, whereas it was only 45% in corals under the high water temperature. Results indicate that higher severity and shorter time scales for bleaching, occurred under abiotic plus biotic stressors. Secondary infection during bleaching may result in heavily damaged corals with less chances of recovery

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1015, Sebel Mossman

Molecular diagnostics of coral exposed to oil and dispersant

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Coral reefs face a variety of stressors with potentially synergistic effects. Understanding the dynamics of these interactions and their impacts on coral health is critical. The Deepwater Horizon (DWH) event in 2010 highlights the need to understand the biological impacts of oil and dispersants in coral ecosystems. The combination of oil and dispersants creates a complex mixture of toxic contaminants with different modes of action on marine organisms through multiple routes of exposure. Studies suggest that oil induced mortality is delayed in corals, indicating that short-term tests measuring physiological responses may not be sufficient to quantify sublethal effects. Exposure to toxicants induces molecular and biochemical processes that can serve as biomarkers of exposure. Such sublethal, molecular quantifications can identify the impacts of oil and dispersant toxicity on coral health. This study examined the effects and interactions of DWH oil, dispersant (Corexit 9500A), and black band disease (BBD) on the coral *Montastraea faveolata*. Variable susceptibility to BBD and dispersant was observed, but no significant results were observed in response to oil. Dispersant and BBD exposures had greater effects on zooxanthellae density and chlorophyll content than oil exposure. In addition, dispersant had a significantly negative effect on BBD severity. Both microarray-based gene expression profiling and bacterial community profiling were used to determine changes in coral health resulting from the treatment stressors and for monitoring potential exposure in the field. Ongoing work will identify specific genotypic traits that may contribute to coral resiliency following oil and dispersant exposures.

4C Coral reef response to multiple stresses: organisms to ecosystems
Thursday 12 July, 1645, Sebel Mossman

Impact of the 2009 tsunami in American Samoa

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On Sept. 29, 2009, a large earthquake in the Tongan Trench produced a tsunami that struck the Samoan archipelago about 20 minutes later. Maximum wave runup was about 12-14 meters in some bays, similar to that of the tsunami in Ache, Indonesia, two years earlier. The Ache tsunami was the first tsunami in which effects on coral reefs were studied, however there were very few baseline transects to measure effects quantitatively. Tutuila had a rich record of baseline transects available, taken in several monitoring programs. Observations of 39 reef sites showed that sites with little or no damage were most common, and sites with heavy damage were least common, similar to the pattern of damage on land. However, reef damage was not correlated with damage on land, with some sites having heavy damage of one without much damage of the other. Heavily damaged reef sites included a

staghorn bed in a reef pass that was obliterated, mobilization of large areas of previously existing rubble in a bay (Fagatele Bay National Marine Sanctuary), scouring by waterfalls off reef flats in another bay (Vatia), sections of a mixed table and staghorn community that were destroyed while nearby sections were largely untouched in another bay (Leone), and large areas of plate corals on a deep slope that were completely removed and destroyed. Most baseline transects did not show detectable change, but transects in one bay (Vatia) showed coral loss, and a transect on the deep plates showed large coral losses.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1035, Sebel Mossman

Synergetic effect of herbicide and sedimentation on coral and its distribution in Shiraho reef

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The likelihood of future degradation of coral reefs caused by artificial chemicals such as herbicide and pesticides is very high. Diuron (N' - (3,4-dichlorophenyl)-N,N-dimethylurea) is one of the active substance contained in a herbicide. The amount of diuron used in Okinawa, is the second highest in Japan. Moreover, diuron has been used recently in antifoulant of ships as a replacement for organotin compounds. We investigated seasonal variations in herbicides contained in water and sediment around coral reef areas in Ishigaki Island in Okinawa Japan, and carried out experiments to see the synergetic effect of herbicide and sedimentation on coral metabolism of photosynthesis and calcification. Samples from twelve stations in the Shiraho reef and five in the Todoroki River were taken seasonally. Diuron and other active substances were extracted using a solid-phase column and measured with liquid chromatography with tandem mass spectrometry (LC'MS/MS). Higher diuron levels, of 1176 ng/L, were detected at Todoroki River in August. However, metabolic activity of coral colonies falls in response to significantly lower levels of diuron in reef water, and diuron in the reef sediment was higher than that in the water. Red soil from sugar cane fields, easily flows out to and accumulates on the reef, especially in the rainy season. Resuspended soil and eluted herbicide may have a synergetic effect on coral. The results of the synergetic effects of diuron and red soil will be discussed.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1415, Sebel Mossman

Temperature dependence of respiration rate of larvae and adult corals

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Planulae of *Acropora tenuis* inoculated with homologous symbionts showed higher sensitivity to thermal or light stresses than non-symbiotic larvae. Algal symbionts may become a source of reactive oxygen species under stress and symbiotic planulae may suffer oxidative stress. Our question was how zooxanthellate planulae of corals with a vertical mode of symbiont transmission, like *Pocillopora damicornis* manage this problem. We found that zooxanthellate planulae of *P. damicornis* are much more stress tolerant than zooxanthella-free *A. tenuis* planulae. In an attempt to elucidate the mechanisms that make *P. damicornis* planulae highly stress tolerant, we compared temperature dependence of respiration rate between planulae of the two species. We also compared temperature dependence of respiration between larvae and adult branches. The respiration rate of adult branches increased in the range of 25-32℃ with the Q10 value for respiration of 2.21 and 1.94 for *A. tenuis* and *P. damicornis*, respectively. Planulae of both species had lower respiration rate and smaller Q10 values than adult colonies. This suggests that larvae have a higher capacity to tolerate a wide temperature range than adult colonies. The Q10 value for respiration of *A. tenuis* was higher than that of *P. damicornis* in both adult and larvae, though respiration rate itself was higher in *P. damicornis* than in *A. tenuis*. Other antioxidant systems and physiological properties of the symbionts might be also responsible for the different stress tolerance between the species.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1215, Sebel Mossman

Cell death in larvae of *Pocillopora damicornis* under thermal stress

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Symbiotic coral larvae may suffer oxidative stress under thermal or light stressors, as algal symbionts can become a source of reactive oxygen species (ROS) under stress. It is a critical question, how zooxanthellate larvae of corals with a vertical mode of symbiont transmission like *Pocillopora damicornis* manage this problem. The objective of this study was to investigate cell death mechanisms in *P. damicornis* larvae under thermal stress. We analyzed abundance and distribution of apoptotic

host cells within *P. damicornis* larvae kept at normal (27℃) or high temperatures (31 and 32℃) using TUNEL assay. Zooxanthellate planulae of *P. damicornis* survived for two weeks at high temperatures (31 and 32℃), though algal density decreased significantly at 32℃. The labeling index, that is, the ratio of TUNEL-positive host cells to DAPI-stained total host cell nuclei, was higher in the gastrodermis than in the epidermis in both the control and high temperature treated larvae. The labeling index in the gastrodermis was highest in larvae treated at 31℃, while the labeling index in the epidermis remained at a low level regardless of the temperature. The present results suggest that ROS produced by symbiotic algae under thermal stress induces apoptosis of adjacent host cells. The low labeling index in the bleached larvae might be due to decreased production of ROS resulting from loss of damaged symbionts from the host tissue.

4C Coral reef response to multiple stresses: organisms to ecosystems
P038

Increased reactive oxygen species and antioxidant enzyme activities with environmental stressors

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Various stressors induce the formation of reactive oxygen species (ROS) in biological cells. In addition to stress-induced ROS, we studied the photochemical formation of hydroxyl (OH) radicals, the most potent ROS, in coral tissues using phosphate buffer extracted solutions and a simulated sunlight irradiation system. OH radical formation was seen in extracts of both coral host and endosymbiont zooxanthellae. This study is the first to report quantitative measurements of OH radical photoformation in coral tissue extracts. Our results indicated that whether or not coral bleaching occurred, coral tissues and symbiotic zooxanthellae have the potential to photochemically produce OH radicals under sunlight. However, no significant difference was found in the formation rates of OH radicals between corals incubated under different temperatures and irradiance. OH radical formation rates were increased by about 60% by increasing UV radiation in the illumination. It was indicated that UV radiation stress strongly affected OH radical formation in coral tissue and zooxanthellae, in addition to its formation through photoinhibition processes. On the other hand, cellular response to the formation of oxygen radicals has many defense mechanisms that include the increased activity of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPX), ascorbate peroxidase (ASPX). These antioxidant enzyme activities were increased by environmental stressors such as high temperature. Especially against hydrogen peroxide with high temperature, host coral increased CAT activity, and zooxanthellae increased ASPX activity. It is considered that stress responses of coral colonies are a result of balances in produced ROS and antioxidant activities.

4C Coral reef response to multiple stresses: organisms to ecosystems
Thursday 12 July, 1755, Sebel Mossman

Community shift from stony coral to soft coral in acidified water

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The anthropogenically increased partial pressure of CO_2 (pCO_2) is absorbed in the ocean and causes its acidification and decreases the saturation fraction of calcium carbonate, inhibiting calcification of coral reefs. An ecosystem shift in coral reefs from stony corals to macroalgae has been suggested as one outcome, but no actual cases have been described. Here we show an ecosystem shift from a stony to a soft coral population in volcanically acidified semi-closed water at Iwotorishima Island. Stony corals were found only in the area with little or no influence of acidification, whereas the high pCO_2 area (800 µatm) was dominated by soft coral *Sarcophyton elegans,* with 50 % coverage. In the highest pCO_2 area (1465 µatm), neither stony corals nor soft corals survived. This field observation was supported by a CO_2-enrichment culture experiment of the soft coral collected at this island, in which calcification rate was unaffected and photosynthetic rate was incremented at 1000 µatm pCO_2, while some colonies died at 2000 µatm. Present field observation and culture experiments suggest that pCO_2 level (>1000µatm) provided favorable conditions to soft coral, but unfavorable for stony coral. Because soft corals only have tiny spicules, they are more resistant to acidification than stony corals. However, higher pCO_2, exceeding 1800 µatm is detrimental for both stony and soft corals. These results infer a shift from stony to soft corals in the future, with high pCO_2 oceans.

4C Coral reef response to multiple stresses: organisms to ecosystems
Thursday 12 July, 1700, Sebel Mossman

Impact of natural and anthropogenic perturbations on the benthic compartment functioning

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Many contemporary coral reefs increasingly fail to regenerate after natural or anthropogenic perturbations and undergo a shift to an alternate trophic state. Understanding nutrient origin and transfer, as well as community trophic structure are key elements for predicting the future of these complex ecosystems facing local and global perturbations. Studies of organic matter fluxes in coral reefs are historically based on physical and biogeochemical approaches. It is therefore important to link these approaches to community analysis, as the abundance of species and populations (e.g. algae) or trophic groups (e.g. filter-feeders) can have a profound effect on nutrient fluxes and budgets. Recent applications use trophic network analysis of element fluxes to predict significant change in the structure and function of reef communities. Food-web length, as one variable of the trophic network, influences ecosystem functioning and diversity, and food-web stability or contaminant accumulation. First, we investigated the effect of a strong physical perturbation (hurricane Gamède) on the characteristics of organic matter reservoirs (water column and sediment) and the benthic trophic network (macro-invertebrates) of a coral reef in Reunion Island. Second, we compared the food-web length of the benthic compartment from two contrasting reefs in the SW Indian Ocean: (1) Reunion Island, highly populated and affected by multiple perturbations, and (2) Glorioso Island, uninhabited and exempted from any direct anthropogenic influences. The benthic compartment was studied through community structure analysis, and carbon and nitrogen stable isotopic composition determination. Conclusions were drawn at the organism and ecosystem levels, and bio-indicator species (e.g. holothurians) were identified.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1400, Sebel Mossman

Fluorescent protein content and stress tolerance of a coral

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Some fluorescent proteins in corals have been reported to have photo-protective as well as antioxidant functions. Green (Gs) and brown (B) morphs of the coral *Galaxea fascicularis* have different content of green fluorescent protein (GFP, Ex 507 nm, Em 515 nm) though they are found side by side at shallow reefs in Okinawa. Polyps of the Gs morph had green fluorescent pigments at the oral disc, and showed much higher fluorescence intensity/unit soluble protein than B morph polyps. To understand the function of the GFP in the stress response of the coral, we exposed polyps isolated from B and Gs morph colonies to high temperature (32℃), strong light (1000 µmol m^{-2} s^{-1}), high temperature and strong light (32℃, 1000 µmol m^{-2} s^{-1}), and the control (26℃, 100 µmol m^{-2} s^{-1}) for 3 h. Polyps were then allowed to recover for 6 h under the control condition. Photochemical efficiency (Fv/Fm) was measured using a mini-PAM before and after stress treatment, and after recovery. Although the GFP content was markedly different between B and Gs morphs, polyps of both morphs showed a similar decrease in the photochemical efficiency after strong light treatment. The present results suggest that the fluorescent protein does not increase tolerance of polyps to strong light in *G. fascicularis*. Green fluorescence diminished when Gs colonies were kept under weak light for a few weeks. This suggests that the GFP has some function under strong light condition, but further studies are necessary to elucidate the function of GFP in the coral.

4C Coral reef response to multiple stresses: organisms to ecosystems
P039

A coral-reef ecosystem model: short-term responses against the multiple stresses

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A coral reef ecosystem model has been developed to evaluate the responses of coral reef communities to multiple stressors. The model is a mass-balanced one-dimensional box model, and the compartments of the model are coral, seagrass, macroalgae, phytoplankton and zooplankton. The metabolic rates (photosynthesis, calcification, nutrient uptake, organic matter release, etc.) of each compartment depend on environmental parameters (water temperature, photon flux density, CO_2 system parameters, nutrient concentrations, water velocity, suspended sediment, etc.) in this model. The parameters in the model were estimated and validated by mesocosm experiments using *in situ* large (W 2.4m x D 1.2m x H 0.9m) and small (W 1.2m x D 0.5m x H 0.3m) size incubation chambers, each of which was equipped with an internal velocity-controlling system. These chambers were deployed on some coral reef communities of the Shiraho reef (well-developed fringing reef), Ishigaki Island, Japan. The experiments were executed under various flow and nutrients conditions, etc., to collect the data on the metabolic rates. The parameters were estimated and validated by these datasets. Moreover, the model was extended to a three-dimensional model coupled with three-dimensional water circulation model, Princeton Ocean Model (POM), incorporating a surface wave deformation model. This extended 3D ecosystem model was applied to the Shiraho coral reef. The

model outputs were compared with time-series and spatial observation data.
4C Coral reef response to multiple stresses: organisms to ecosystems
Thursday 12 July, 1630, Sebel Mossman

Variation of growth and symbiont photosynthesis among corals

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Colony size is vital information to estimate the approximate age and potential longevity of reef-building corals. For example, large and massive Poritid corals are often considered to be longer lived than that of smaller ones. In our study, small clone colonies (1.5 x 1.5 x 1.5cm in size) of *Porites australiensis* divided from five parental colonies (approx. diameter of 1m) were reared for about six years under outdoor aquarium conditions, and their photosynthesis and growth rates have been monitored during the period. Despite uniform environmental conditions, prominent variations among clones were observed. Interestingly, results of pulse amplitude modulation (PAM) measurements indicated the ones with less growth had greater variation of photosynthetic efficiency with relatively large seasonal changes. These clone-dependent variations are potentially important for the coral populations in sub-tropical region where corals would experience highly variable environmental conditions daily, monthly and seasonally.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1230, Sebel Mossman

Specific bleaching of Pocilloporidae corals in low water temperature

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Coral bleaching is the most crucial environmental disease influencing the decline of coral reef ecosystems of the world. This disease is caused by not only high water temperatures, but many other physical causes and/or by some biological causes like the involvement of bacterium. In the recent decade, corals are invading low water temperature (northern) regions of Japan, due to increasing seawater temperature during the winter (Yamano et al., 2011). Regional abalone farming is being disturbed by the invasion of Acroporidae corals which grow over the hard substratum, competing with brown algae to be consumed by abalones (Fisherman's union in Nagasaki, pers. comm.). However, such rapid invasion by corals may not always be successful. From winter 2010 to spring 2011, water temperatures of inshore waters in southern Japan were low compared with earlier, recent years. An extensive coral bleaching was observed in many pocilloporid corals in southern Japan during the spring 2011. Three Pocilloporidae species, i.e., *P. verrucosa, P. meandrina* and *P. eydouxi*, distributed in southern Japan were affected by bleaching while *P. damicornis* and other sympatric coral genera were not. On the other hand, *P. damicornis* which showed an exceptionally wide range of distribution among Pocilloporidae, extending to northern Japan where seawater temperatures were too low to form coral reefs, was affected by low temperatures along with other sympatric species in northern Japan.

4C Coral reef response to multiple stresses: organisms to ecosystems
P040

Benthic-pelagic coupling in a Caribbean reef lagoon affected by hurricane 'Dolly'

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In oligotrophic tropical coral reef environments, tightly coupled benthic-pelagic material fluxes represent key biogeochemical processes sustaining high benthic productivity and overall ecosystem functioning. Tropical storms in the Caribbean (i.e. hurricanes) can severely impact and shape the physical and chemical state of marine coastal ecosystems. Although hurricanes occur as frequent climatic phenomena and cause large-scale habitat devastation, there is no information regarding their influence on ecosystem metabolism and benthic-pelagic coupling in coastal coral reef environments. Thus, this study investigates these processes in a typical Caribbean shallow water reef lagoon close to Puerto Morelos (Mexico) over the course of the tropical storm 'Dolly' (2008). Pelagic and benthic lagoon metabolism were assessed at high temporal resolution by measuring oxygen fluxes along with dissolved organic carbon (DOC), particulate organic matter (POM) and chlorophyll a concentrations in lagoon waters. POM sedimentation rates were additionally quantified by trap deployments. Our preliminary findings characterize the studied reef lagoon as an overall heterotrophic environment, and reveal pelagic and benthic compartments are largely decoupled under undisturbed conditions. Further, we show the first evidence for a storm event significantly impacting pelagic and benthic lagoon metabolism. The planktonic community exhibited highest respiration shortly after the storm

and a strong correlation to the subsequent decrease in pelagic DOC levels. The generally net autotrophic benthic community converted to heterotrophy immediately after the storm, while gradually regaining autotrophic dominance within four days. These findings emphasize compartment-specific and rapid responses by reef lagoon communities, with implications for the functioning of benthic-pelagic coupling affected by tropical storm disturbances.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1040, Sebel Mossman

Reconstruction of land-use change effects using coral skeletal proxies in Ishigaki Island, Japan

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Human activities produce various stressors to coral reefs. Especially, the influence of anthropogenic land-use changes cause soil erosion and result in sediment terrestrial input of river runoff into a coral reef. However, it is difficult to estimate the long-term trend of anthropogenic terrestrial input to coral reefs. In this study, we reconstructed river runoff events onto coral reefs using geochemical proxies in coral skeletons. We collected two coral cores by drilling live I colonies at the mouth of the Todoroki river in Ishigaki Island of southwest Japan (24°23'N 124°15'E) in September 2007 and September 2009. We obtained X-ray and luminescence images of 5mm thick core slabs, to determine the annual bands and maximum growth lines. Coral powder samples, which were milled at 1-mm intervals were subjected to analyses for $\delta^{18}O$, $\delta^{13}C$ by mass spectrometer, and Sr/Ca, Ba/Ca and Mg/Ca ratios by ICP-AES-attached ultrasonic nebulizer. As the results, we got coral geochemical data for the periods of 14 and 50 years for Sep.2007 and Sep. 2009 cores, respectively. Based on coupled analyses of Sr/Ca ratios and $\delta^{18}O$ analysis, we reconstructed sea surface temperature (SST) and sea surface salinity (SSS) changes. Main factors for SSS changes appeared to be precipitation in this area. We also estimated the amount of terrestrial input from Ba/Ca ratios and luminescence bands in coral skeletons. Integrating these geochemical results with land-use history based on multi-temporal aerial photographs and satellite images, we showed the effect of terrestrial input caused by precipitation and human-induced land-use changes.

4C Coral reef response to multiple stresses: organisms to ecosystems
P041

Poor tissue regeneration in corals at a marginal reef site

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Coral species regenerate lesions at different rates, and this has been related to life history strategies, environment conditions and different lesion characteristics. Colony damage and recovery rates are also essential for predicting demographic changes in coral populations. The aims of this study were to quantify the regeneration rates of the coral *Siderastrea stellata* (Verril 1868) under three different levels of anthropogenic stress and compare the regenerative capacity of *S. stellata* to *Mussismilia hispida* (Verril 1902) at marginal reef site in Armação dos Búzios, Brazil. Artificial lesions (approx. 5 cm^2) were inflicted *in situ* on the top of 20 healthy coral colonies per site and species. Colony recovery was monitored monthly by underwater digital photography, and area and perimeter were measured for each lesion. In *S. stellata* lesion sizes increased at all sites during the first four months and the pattern of recovery was different between sites, especially among census times. Up to 120 days post-lesion the least anthropogenically stressed site showed the lowest coral recovery rate. Regeneration rate depended on the species involved as *S. stellata* with smaller polyps regenerated more slowly than *M. hispida*, a larger polyp species. Monitoring longer-term regeneration appears necessary. These findings confirm that the genus Siderastrea is a poor regenerator of surface lesions. Since slow recovery rates increase the chance of whole colony mortality, this information has important implications for coral health and coastal marine management.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1030, Sebel Mossman

Coral mucus: a potential bioindicator of reef health?

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A major criticism of population and community level indicators of coral reef condition is the lag time between exposure to critical levels of sublethal stress and a visible response. There is increasing awareness that rapid, early-warning indicators are of greater relevance since these provide more active mitigation and therefore greater chance of recovery. Direct measures of sublethal condition often have logistic limits for monitoring over larger temporal and spatial scales (e.g. pulse amplitude modulated fluorometry) or involve destructive sampling, and may in themselves represent a stressor to the corals. Despite a large body of

evidence from pathological perspectives linking coral mucus content to coral condition, there have been few attempts exploring its value as a monitoring tool. The aim of this study was to investigate the reliability of coral mucus content as a bioindicator of reef health with regard to suspended and settling sediments in Singapore. We present results for *Acropora latistella, Pectinia paeonia, Echinopora lamellosa* and *Favites abdita* that were determined using modified flow cytometric protocols for zooxanthellae, chlorophyll pigments and RNA/DNA ratios. The results are discussed in context of sensitivity and reliability.

4C Coral reef response to multiple stresses: organisms to ecosystems
Thursday 12 July, 1750, Sebel Mossman

Rising sea temperature could cause reduction in protective mucus of corals

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The surface muccopolysaccharide layer (SML) of scleractinian corals is thought to play a key role in coral innate immunity, acting as a defense against UV light, sediment deposition, and potentially pathogenic bacteria. The SML also provides a barrier against harsh environments at low tides or other external stressors coral may encounter. Recently it has been shown that coral SML exhibits antimicrobial activity. One question in coral biology is how rising sea surface temperatures may affect the production of coral SML. In this laboratory study we investigated SML production by three Caribbean coral species, *Diploria strigosa*, *D. labyrinthiformis*, and *D. clivosa*, over a temperature gradient. Ambient temperature (25°C) in experimental aquaria was raised to 31°C over a two-week (rapid) period and a seven-week (slow) period. Mucus thickness was visualized under a boom microscope after allowing black activated carbon particles to settle on the coral surface, and then measured using a micropipette attached to a micromanipulator. Measurements were made at a resolution of 10 µm. All three species showed a significant decrease in mucus thickness with elevated temperature, regardless of the rate of temperature change. There was no significant difference in the decrease in mucus production between species, suggesting that the SML of all *Diploria* species is highly sensitive to temperature. The potential for a reduction in the SML of scleractinian corals with the observed steady increase in seawater temperature associated with global climate change may have major implications for coral health and their ability to withstand biotic and abiotic stressors.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1000, Sebel Mossman

Coral pheno- and genotypic characteristics along an environmental gradient

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The geographic distribution of a coral species depends in large parts on its degree of plasticity towards prevailing environmental conditions. All members of the coral holobiont - bacteria, zooxanthellae and coral host - contribute to the capacity for habitat acclimatization and/or adaptation. We have surveyed an area of approximately 1,200 km^2 in the Central Red Sea in order to characterize fore- (ocean-facing) and back- (land-facing) reefs in near-, mid- and offshore settings. Despite pronounced ecosystem differences, fungid corals were present at all sites. Therefore each reef was sampled for specimens of two family representatives (*Fungia fungites* and *Ctenactis echinata*) to examine their metabolic and biogeochemical properties, as well as abundances and diversity of their associated symbionts (bacteria and zooxanthellae). Altering environmental conditions appear to promote not only distinct physiological, but also genetic modifications of the coral holobiont. Strategies of habitat adjustment are complex and involve phenotypic acclimatization such as variations in zooxanthellae densities, pigment concentrations, or lipid compositions. However, genotypic adaptations of the holobiont might also play a role. We assume that not only the presence of certain zooxanthellae clades varies with the environmental gradient, but also that the coral-associated microbial communities differ as a response to habitat change. Our findings show a remarkable variety and potential for phenotypic acclimatization and genetic adaptation in response to ecosystem variance, and hence might serve to better understand reef functioning and coral resilience in regard to environmental changes worldwide.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1445, Sebel Mossman

Long-term responses of coral reefs chronically disturbed by runoff

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Products of terrestrial runoff are considered one of the most significant threats to the Great Barrier Reef (GBR) as intensifying river and stream discharge can lead to increased levels of nutrients, pollutants, sediments and turbidity affecting coral reef ecosystems. While deleterious and immediate effects of river runoff on coral communities have been well documented, there is a generalized lack of historical information on the frequency and intensity with which the GBR has been influenced by river discharges. Further, long-term responses of coral reefs to these events are not yet fully understood. To address these issues, the Spectral Luminescence Scanning (SLS) technique was applied on five *Porites* coral cores from the Keppel Islands (Southern Great Barrier Reef). This technique quantifies the signal of soil-derived humic acids transported to the reef during major flood events. We obtained an 80-year chronology record (1930-2010) of luminescence intensities as an indicator of Fitzroy River discharge to the Keppel reefs. Our results suggest these reefs have been chronically influenced by freshwater along the reconstructed period. We found the 12 highest luminescent peaks were strongly correlated with the timing of significant flood events recorded at Rockhampton (from Fitzroy River). Data on benthos structure revealed vigorous coral communities around Keppel Island and suggest these reefs are resilient to recurrent runoff events. Our findings not only increase the knowledge on the river discharge regime into the GBR during the last century, but also provide new insights to understand long-term resilience processes on reefs subjected to chronic disturbances.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1130, Sebel Mossman

Enzyme activity and metal bioaccumulation of *Montipora digitata* under stressor

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The antioxidant enzymes have a role to remove reactive oxygen species caused by some stressors, such as high temperature. Superoxide dismutase is one of the antioxidant enzyme contained in corals. This enzyme has trace elements such as Zn, and Cu at the center of the molecular structure as a cofactor of the activity. When excessive active oxygen is produced from stress, it is thought that the coral needs more antioxidative enzymes and hence center metals, to produce the enzymes against active oxygen stress. Coral bleaching is caused by active oxygen generated by high temperature and light. Therefore, the antioxidative and trace metal elements may be a key factor in the stress response of coral bleaching and stress tolerance. This study is to clarify the role of some trace metals of antioxidative enzymes in metal enriched coral under high temperature stress conditions. *Montipora digitata* were incubated in seawater enriched with metals, at a concentration at which coral metabolism of photosynthesis and calcification were not affected. Metal concentrations in the tissues and zooxanthellae were determined using a dialysis membrane isolation and ICP-MS method. Superoxide dismutase (SOD) was measured. The trace metal detected in coral at relatively higher concentrations was zinc. Photosynthesis and calcification of coral incubated in seawater enriched with Zinc chloride ($ZnCl_2$), decreased at concentrations over 1 ppm. However there was no toxic effect at 0.1 ppm of $ZnCl_2$. SOD activity of corals incubated under the 0.1 ppm $ZnCl_2$ and 31-32℃ high temperature conditions were significantly lower than the control group.

4C Coral reef response to multiple stresses: organisms to ecosystems
P042

SymbioCoRe: an initiative to promote collaborative coral research

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Fundamental questions as to how the cnidarian host, dinoflagellate symbiont and the associated microbial community interact within the 'coral holobiont' and with their environment as a whole, are the focus of research worldwide. An integrated approach is widely recognized as essential to study coral ecosystems in their entireness, but lasting interdisciplinary collaborations are often hampered by the lack of funding for the transfer of knowledge and expertise through the international exchange of staff, workshops and seminars. As such, a new concept 'SymbioCoRe' has been introduced to build an integrated international research network. SymbioCoRe is a three-year initiative funded by the EU through the International Research Staff Exchange Scheme (IRSES), to facilitate multidisciplinary collaborations between European and Non-European partners with expertise ranging from coral genetics, through coral photobiology to ecophysiology and reef biogeochemistry. Key topics addressed by the SymbioCoRe partners include: (i) the effects of climate change on coral reef primary production, respiration and coral photo-physiology; (ii) the influence of photoacclimation patterns on the coral bleaching potential; (iii) changes in microbial

diversity, activity and function between healthy and deteriorating coral reefs and (iv) the ecological and biogeochemical consequences of phase shifts in coral reefs. By presenting SymbioCoRe to a broader scientific audience it is aimed to introduce the consortium and the research questions that have been driving this initiative, and to draw attention to the opportunities that programmes such as IRSES offer in promoting international collaborative efforts, and to reach out to scientists from related fields for wider future collaborations.

4C Coral reef response to multiple stresses: organisms to ecosystems
P043

Will the accretion-erosion balance persist? Effects of microhabitat variation on bioerosion

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Coral reef ecosystems persist in an accretion-erosion balance. While corals and other calcifying organisms accrete calcium carbonate skeletons, bioeroders break down this framework by grazing on or boring into the reef structure. Management efforts to sustain coral reef ecosystems are often focused on coral health and growth rates; however, the resilience of reefs also depends on bioerosion rates and their response to local and global human impacts. A persistent challenge for coral reef scientists is to distinguish the effects of climate change from other forms of environmental variation. In this context, we studied the small-scale natural variation of the physico-chemical environment in a lagoon reef habitat in Kaneohe Bay, Hawaii and determined how this variation affects bioerosion rates. To further the study of bioerosion, we used novel technologies to advance the study of bioerosion beyond the limits imposed by traditional methods (i.e. buoyant weights). Using micro-computer-aided tomography, we were able to calculate highly accurate bioerosion rates from micrometer-scale 3-dimensional images of calcium carbonate blocks. We then correlated these bioerosion rates with a suite of high resolution environmental sensors that measure microhabitat variation in pH, salinity, temperature, oxygen, water flow, and other parameters at the small scales experienced by bioeroder communities. We specifically focus on the relationship between small-scale variation in pH and bioerosion rates, which may be an important indicator of reef response to ocean acidification and thus the ability of coral reef ecosystems to maintain their delicate accretion-erosion balance.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1430, Sebel Mossman

Energy needed by corals for survival

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The existence of corals over millions of years depends on the ability of the zooxanthellae, the host, and the holobiont - as a whole unit - to change, acclimate, and adapt, in order to survive under developmental and stress conditions. The advantage of symbiosis is based on the trading of energy for strategic material, and on the transport of energy and nutritional resources between the host and the zooxanthellae. This allows corals to be spread all over the tropical, and some temperate oceans. The energy flow in the symbiotic association between zooxanthellae and the coral mainly depends on light intensity, where most of the holobiont energy can be supplied from sunlight, but only partially under low light intensities. Under eutrophication conditions, the energy flow changes, the zooxanthellae use the photosynthetic energy for their own growth, leading to a reduction in the animal growth rate. Under stress conditions that cause bleaching, such as high temperature and high UV, in most cases, the first step of this energy flow causes damage, in other words, the photosynthesis processes are blocked and symbiosis breaks down. Future survival of the coral reefs depends on the ability of the holobiont to keep its energy in balance.

4C Coral reef response to multiple stresses: organisms to ecosystems
Thursday 12 July, 1745, Sebel Mossman

The effect of thermal stress anomalies on the diversity of *Symbiodinium* communities in Oahu, Hawai'i

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Corals respond differently to environmental disturbances such as elevated seawater temperature, but the extent to which such environmental factors influence *Symbiodinium* community diversity and functional range in corals, remain under explored. The frequency of Thermal Stress Anomalies (TSAs) recorded over a 20 year period from 1985-2005 reveal thermal heterogeneity across the Hawaiian archipelago and higher thermal stress in the southern part of the island chain. *Monitpora capitata* is an important reef building coral in Hawaii that hosts very variable *Symbiodinium* communities and interacts with clade C or clade D *Symbiodinium*, or both simultaneously. This makes this species an excellent subject to examine how *Symbiodinium* communities reflect the 20-year thermal history of their environment. Our data indicate that *Symbiodinium* sequence diversity in M. capitata differs with frequency of TSAs as well as with salinity and local anthropogenic sedimentation. At low and high frequency TSA sites, clade C and D *Symbiodinium* sequence types

are dominant, respectively. The total diversity of *Symbiodinium* sequence types is also lower in corals hosting clade D sequence types. Our results are discussed in the context of competition among *Symbiodinium* types, the implications of opportunism in coral-*Symbiodinium* associations and the functional attributes and survivability of different coral *Symbiodinium* unions.

4C Coral reef response to multiple stresses: organisms to ecosystems
Thursday 12 July, 1730, Sebel Mossman

Carbon/nitrogen allocation between coral and zooxanthellae

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Corals are affected by thermal stress, mainly through modification of their metabolic processes such as photosynthesis, respiration and the symbiotic relationship with their zooxanthellae. Little is known about the allocation of organic carbon and nitrogen between both, coral host and symbionts, under normal and high temperature stress. The purpose of this study is to investigate effects of heat stress on organic carbon and nitrogen allocation between zooxanthellae and corals tissues. Twenty nubbins of the coral *Montipora digitata* were used for experiments under normal and heat stress (20℃, 28℃, 32℃) conditions in 2009. Corals were incubated using natural seawater for three days under 12 h light/12 h dark with photon flux density of 270 µmol m^{-2} s^{-1}. At the end of experiments coral tissues were removed by water pick and zooxanthellae were separated from coral tissues by centrifugation and purification. POC (Particulate Organic carbon) and PON (Particulate Organic Nitrogen) in zooxanthellae and host tissues were measured. POC and PON concentrations increased to 678 and 67.5 nmol cm^{-2} in host tissues and 433 and 88.2 nmol cm^{-2} in zooxanthellae during the experiments at 20℃ with C/N ratios of 10 for host and 4.9 for zooxanthellae. However at 32℃, POC concentrations also increased to 1107 nmol cm^{-2} in host tissues and 134 nmol cm^{-2} in zooxanthellae, but PON concentrations decreased to 43.1 in host and 16.5 nmol cm^{-2} in zooxanthellae, indicating a decoupling between carbon and nitrogen cycles resulting in a more rapid N cycle under thermal stress.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1115, Sebel Mossman

Experimental response variation among coral species to ocean acidification

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Increasing atmospheric CO_2 concentration is decreasing seawater pH and calcium carbonate saturation, which is now termed ocean acidification. Previous studies have demonstrated that ocean acidification decreases coral calcification rates and affects their skeleton formation, and hence has negative impacts on the coral reef ecosystem. However, most of these studies have been conducted under controlled temperature and light conditions, which does not exactly reflect field conditions. In this study, to understand the effects of ocean acidification on corals under near field conditions, *Acropora digitifera* was cultured under three CO_2 concentration (380, 1,000, 2,000 atm) for 5 weeks in natural sunlight and temperature conditions. Coral growth rate was measured by buoyant wet weight, and calcification, photosynthesis and respiration rate using pH-total alkalinity anomaly technique. Furthermore, photosynthesis efficiency and zooxanthellate density were also examined. As a result, we found no significant effects on all studied factors between the three CO_2 conditions. From present results, we suggest that high natural sunlight condition may eliminate effects of ocean acidification by stimulating the coral calcification rate. However, there is also a possibility that *A. digitifera* is highly tolerant to high CO_2 compared to the other corals. To elucidate these hypotheses, we evaluated the effect of high CO_2 on *A. digitifera* and *Montipora digitata* cultured under artificial light conditions. In this presentation, we will discuss the effects of acidification experimental methodology and intra-species responses of corals to ocean acidification.

4C Coral reef response to multiple stresses: organisms to ecosystems
P044

Reef-related fauna stressed out? Insights from experiments

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Seas subjected to global warming, acidification and various anthropogenic influences are seas of change. Coral reef communities are especially vulnerable to temperature increase. Whereas bleaching events are an alarming response of stress in hermatypic corals, adverse effects are less obvious in other reef-related species. Different levels of sensitivity towards various stressors may lead to the survival or decline of a species, causing subsequent shifts in species interactions. Experimental approaches help to understand organism responses to natural factors as well as

anthropogenic stressors, and to explain and predict changes in community compositions. From 2008 until 2011 we conducted a series of experiments in the Marine Habitat Laboratory at Bogor Agricultural University to investigate the stress response of Indonesian reef-related fauna. The main emphasis had been on temperature tolerance in anthozoans, echinoderms and molluscs, but we also looked at stress effects caused by species interactions. Stress tolerance towards increasing temperature was determined by survival rates, locomotion and activity patterns. An example of ecological consequences is given by the response of reef-related macroalgae towards grazing pressure by gastropods. The results show that tolerance levels seem to be manifold, and that there are differing patterns. The experiments also put strong emphasis on the need for research on multi-stressor effects. The long-term survival of a species will depend on the ability to adapt to a multi-stressor environment. The pattern of tolerance levels under increasing environmental stress will either sustain or even promote a high biodiversity, or lead to species loss.

4C Coral reef response to multiple stresses: organisms to ecosystems
Friday 13 July, 1245, Sebel Mossman

Theme 5. Technologies for coral reef science

5A Remote sensing of reef environments

Great Barrier Reef phytoplankton bloom dynamics derived from satellite data

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Spatial and temporal mapping of phytoplankton bloom dynamics in coastal waters from ocean colour satellite data is relevant to coastal managers because information on the timing, location and concentration of algal blooms are key indicators for assessing coastal ecosystem health. In the Great Barrier Reef (GBR) waters, phytoplankton growth is primarily limited by nutrient availability and may increase as a response to river flood plumes containing sediments, nutrients, and other dissolved and particulate organic matter. Climatology maps, latitude-time plots, and time-series of satellite-derived proxies for phytoplankton concentrations and algal surface expressions (e.g., *Trichodesmium* sp.) were derived from weekly composites of MERIS satellite products for the GBR between 2006 and 2011. We show that an increase in phytoplankton biomass dynamically propagates through the lagoon following the tropical wet season. Spatial differences in phytoplankton dynamics were also observed. The northern GBR was characterised by a higher frequency in its Chlorophyll signal, likely due to more frequent wet tropics freshwater discharges. In comparison, Chlorophyll had a lower frequency and was strongly associated with seasonal river flows in the southern GBR. The coastal enclosures of the Fitzroy, Mackay, and Burdekin displayed the highest variability in Chlorophyll, while the oligotrophic lagoon was comparatively stable throughout the years. Surface blooms occurred mainly in the southern GBR, with higher frequency before the start of the wet season. Processes such as tidal mixing, bathymetry, and flood events were the main drivers of the phytoplankton biomass in the GBR waters.

5A Remote sensing of reef environments
Monday 9 July, 1715, Sebel Mossman

Microphytobenthos and their spatial and temporal dynamics in Heron Reef

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Our capacity to understand complex processes occurring on coral reefs is hampered by the spatial and temporal variability of their components. Microphytobenthos (MPB) are highly variable microbial associations that inhabit benthic sediments on coral reefs and mediate essential biogeochemical processes in the reef ecosystem. This work uses satellite image data sets, combined with field data, to map and predict the spatial distribution of MPB over time in Heron Reef, a lagoonal platform reef in the Great Barrier Reef, Australia. Several different types and scales of satellite images (Quickbird, Landsat Enhanced Thematic Mapper and Chris-Proba) were evaluated for mapping MPB extent and cover levels. The comparison between map accuracies obtained from each dataset allows the selection of a suitable satellite time series to conduct the multi-temporal study. Field data included: 1) pigment determinations (e.g. Chlorophyll *a*) as a measure of microphytobenthic abundance and 2) in-situ spectral reflectance of MPB at pigment sampling sites. Measurements of grain size distribution were conducted per sampling sites due to its influence on spectral reflectance measurements. Regression analysis was used to assess the relationship between pigment concentration and spectral reflectance signatures, and to develop a model suitable for application to satellite images to map pigment and MPB concentration. This enabled the production of microphytobenthic abundance maps and the prediction of changes in spatial distribution of MPB over time.

5A Remote sensing of reef environments
Tuesday 10 July, 1645, Sebel Mossman

Spatial analysis of macroalgal cover dynamics in the reefscape

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One major concern in coral reefs at present is the threat of shifts towards an algal dominated state. In order to address this, knowledge of the mechanism driving coral reef macroalgal cover dynamics is needed. Much has been done on coral reef macroalgal cover dynamics but the focus was mainly on temporal dynamics of macroalgal growth. Thus, current knowledge is based on these studies. However, another important component in the macroalgal growth dynamics involves spatial dynamics, or understanding how macroalgae increases its cover in a given reefscape over time, and this has only been studied at spatial scales of

centimetres to metres using quadrat and transects. Spatial dynamic analysis of macroalgal growth is best done using spatially continuous measurements of change of the studied area, as these would completely show the amount of spatial heterogeneity in macroalgal cover change. In this study, spatial dynamics of macroalgal cover were measured from field monitoring data and a time series of high spatial resolution multispectral remote sensing imagery. The study site was a 200,000 square meter reef flat area at Heron Reef, Southern Great Barrier Reef, Australia. Results revealed: 1) the usefulness of linking field data based changes with changes derived from high spatial resolution multispectral remote sensing imagery, 2) that spatially explicit knowledge of macroalgal cover change derived from a time series of high spatial resolution multispectral remote sensing imagery, and 3) that spatially explicit knowledge enabled quantification of spatial variation of macroalgal cover changes and associated benthic cover transitions.

5A Remote sensing of reef environments
Tuesday 10 July, 1250, Sebel Mossman

A novel remotely-sensed index for mapping submeter scleractinians over regional extents

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Space-borne remote sensing has resolved critical issues for mapping coral reef structures that human-based and ship-based surveys could not have overcome, namely the data continuity irrespective of the water depth. With the emergence of very high spatial sensors, the spatial capabilities of satellites have outperformed those of aircraft, providing spectral information at the submeter scale and over large areas. The fineness and the quantity of spectral bands allow the airborne sensors to better discriminate among coral reef features over local areas. However, with the launching of the WorldView-2 sensor, coral reefs can now be surveyed using eight spectral bands at the 2 meters and 0.5 meters spatial resolution, either in raw or pansharpened mode, respectively. Complementary to the blue, green, and red bands commonly used, the WV-2 purple and yellow bands have allowed the visible spectrum to be fully detected in five different bands spanning averagely 56 nanometres. The relationships between linear combinations of the five bottom reflectances, *in-situ* and remotely sensed, related to three scleractinian corals (*Acropora* spp. thickets, *Porites* spp. and *Synaraea* spp. bommies) are examined. Regression analysis shows the green-purple difference ratio to be more significant than the other combinations. The so-called Normalized Difference Scleractinian Index (NDSI) is found to be a proxy for the amount of zooxanthellate-borne pigments such as chlorophyll-*a*, chlorophyll-*c*, diadinoxanthin and caroten. Across the scleractinian genus, this novel index holds great promise to map, detect, and predict change in scleractinian reefs at the colony-level scale over regional areas, thereby aiding their management and preservation.

5A Remote sensing of reef environments
Tuesday 10 July, 1745, Sebel Mossman

Detecting island mass effect through remote sensing

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Island mass effect (IME) refers to the enhanced primary productivity that occurs around oceanic islands in comparison to the surrounding waters. There are two types of physical disturbances that may create an IME: 1) the tidal regime around the island, which acts as a stirring rod to enhance vertical mixing locally and break down the pycnocline, and 2) if flow past the island generates eddies downstream and a wake of disturbed flow extends several island diameters away. Phytoplankton blooms in otherwise oligotrophic systems may potentially increase near shore zooplankton that may help reefs cope with stressors such as bleaching events. A study by Palardy et al. (2008) showed that heterotrophic carbon accounted for 46% of some coral species' daily metabolic carbon requirements when healthy and 147% when bleached. Another study by Anthony et al. (2009) showed that high rates of heterotrophy could delay the onset of mortality by up to three weeks. We examined remote sensing data from the Moderate Resolution Imaging Spectroradiometer (MODIS) AQUA for three islands of the Republic of Mauritius in the Indian Ocean from 2008-2011. We found weak IME around the three islands all year round with chlorophyll a concentration ranging from 0.1 to 3.0 mg/m^3. Peak periods of the IME were during April and May. IME is an overlooked aspect of the bio-oceanography in areas near reefs that may have significant implications for reef health, and thus of future management.

5A Remote sensing of reef environments
P045

Underwater hyperspectral imaging of marine structures in shallow coastal waters

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Airborne hyperspectral remote sensing has proven to be an effective means of classifying and mapping large areas of shallow coastal reefs. The hyperspectral nature of the data collected is appropriate for processing by advanced physics-based optical model inversion schemes. These processing methods are used to classify objects

and structures based on subtle differences in their spectral signatures. Habitat maps based on airborne hyperspectral data provide synoptic views of reefs and shallow waters; with corals, sea grasses, algal assemblages, water quality, and bathymetry data displayed at high spatial resolution. However, advanced airborne mapping techniques are only applicable to water depths of approximately 15 metres. There is potential to deploy hyperspectral imagers at great depths in marine environments lit by artificial sources. An underwater hyperspectral imager has been developed at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. Preliminary marine deployments of this instrument have been carried out at Lizard Island on the Great Barrier Reef, and in Hamelin Pool, Shark Bay, in Western Australia. The data algorithms developed for processing airborne data have been adapted to process the underwater hyperspectral imager data in order to allow classification of structures such as corals and stromatolites. We will present an overview of the optical processing techniques applied to the hyperspectral data, as well as preliminary classification maps of reef structures.

5A Remote sensing of reef environments
Tuesday 10 July, 1515, Sebel Mossman

Satellite remote sensing of characterization of Caribbean fish spawning aggregation sites

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Fish spawning aggregation sites at the shelf break of the insular geologic platform of Puerto Rico and the U.S. Virgin Islands have long been exploited by fishers. Aggregation sites such as the Hind Bank in St. Thomas, US Virgin Islands and Bajo de Sico off the west of Puerto Rico, have been historically fished for the commercially important species groupers and snappers. Satellite remote sensing of the ocean allows for the collection of data such as chlorophyll (chl-a), sea surface temperature (SST), coloured dissolved organic matter (CDOM), the attenuation coefficient at 490 nm (Kd 490), and atmospheric properties, among others. Some of these parameters could help explain the specific conditions present at the aggregation sites that could account for the temporal/spatial patterns of the fish aggregations. A time series of these parameters shows the variability at the aggregation sites over a more than 10-year span. This time series could help explain the high fidelity of aggregating fish to these sites. The signal of an unprecedented influx of waters from the South American Rivers also impacted these sites and is documented. Comparing the known aggregation sites with sites where no aggregations take place would help in understanding why these aggregations occur at specific sites. Characterizing the areas using remote sensing techniques would help describe the differences in dynamics at the aggregation and non-aggregation sites. These historical satellite data can then be correlated to the historical catches of these species.

5A Remote sensing of reef environments
Tuesday 10 July, 1130, Sebel Mossman

Enhanced underwater mosaicing technology for coral reef monitoring and mapping

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Underwater landscape mosaics bridge the gap in image-based mapping between airborne imagery, which provides reef-tract-scale information of marine systems, and single-photo imaging of coral colonies by divers. Underwater landscape mosaics are created by acquiring downward-looking images over an area of interest, which are then aligned through sequential and global feature matching algorithms. The end product is a multi-layer dataset consisting of a single-image map covering the area of interest and an integrated layer of close-up images that provide millimeter-scale benthic resolution over the mapped area. Underwater mosaics retain the strengths of diver-based surveys while providing a superior tool for documenting benthic community changes over time. Recent technological advances continue to enhance mosaic monitoring and mapping capabilities. For example, benthic resolution of mosaic maps was increased through the development of a dual 14MP still camera survey platform that simultaneously acquires multi-scale images of the reef bottom. Large area mosaics, up to 5000m^2 in size, can now be created by adding GPS-based ground control points to overlapping small area mosaics of 100-200m^2. In addition, users can now monitor coral resources over several kilometers by conducting hundreds of mini-mosaic surveys in a single day. These miniature mosaics are acquired in under a minute of in-water dive time and cover approximately 25m^2/image. Finally, landscape mosaic algorithms can now be used with low-cost HDV camera systems costing less than $300USD. Recent enhancements in post-processing and mosaic survey designs have increased the flexibility and application scale of underwater mosaicing technology without increasing costs to potential monitoring programs.

5A Remote sensing of reef environments
Tuesday 10 July, 1700, Sebel Mossman

Over a decade of hyperspectral reef remote sensing research in Puerto Rico

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Remote sensing of reef environments has evolved into a robust, highly sophisticated discipline, where geospatial imagery is now commonly utilized across a wide range of fields in reef science. In the interest of continuing to promote and improve the capabilities of reef remote sensing, the University of Puerto Rico at Mayagüez (UPRM) has spent the last decade and more developing advanced image analysis algorithms for deriving environmental and habitat information for reef environments. A central aspect of this research has been development of the SeaBED database, an array of airborne and satellite imagery acquired at multiple temporal, spatial and spectral resolutions over the reefs in southwestern Puerto Rico. A majority of this work is focused on exploring the limits of hyperspectral remote sensing, where differences in spectral characteristics are leveraged to assess nuances in environmental attributes. As supporting information, research has also incorporated collecting accompanying field information, such as habitat distribution, species composition, and *in situ* reflectance characteristics. UPRM has employed this extensive remote sensing database to develop new techniques in image pre-processing, spectral unmixing, image classification, inversion modelling, and data fusion to develop improved analysis tools for benthic habitat mapping. Most recently, work has focused on assessing the capacity to derive biodiversity metrics as a function of spectral diversity. We present a summary of the work that has been accomplished at UPRM in the last decade, with examples highlighting the different achievements, and an overview of directions being followed to continue advancing the field of reef remote sensing.

5A Remote sensing of reef environments
Tuesday 10 July, 1145, Sebel Mossman

Quantifying environmental forcing and exceedance thresholds on coral reefs

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Coral reef ecosystems are exposed to a diverse suite of environmental factors that directly affect coral reef ecosystem function and health. Regional differences in the prevailing climatological conditions strongly dictate spatial distributions in coral reef communities, while the time-dependent variability of environmental forcing leads to ecological changes within the local coral reef community. Proper characterization of the climatological conditions in which coral reef systems exist and the identification of ecologically relevant exceedance thresholds on coral reef ecosystems are critical, if we are to understand the dynamics and implications of abiotic-biotic interactions on reef ecosystems. Combining bathymetric information with remotely-sensed sea surface temperature, chlorophyll-*a* and photosynthetically available radiation data and modeled wave data, we present a methodological approach to develop spatially constrained, island-specific metrics, with a focus on Pacific island ecosystems. These metrics quantify environmental forcing and exceedance thresholds for ecologically relevant forcing events. The derived metrics enable a basin-scale spatial assessment of coral reef exposure to environmental forcing and a determination of both the magnitude and frequency of threshold exceedance forcing on coral reef communities. Given the current barrage of anthropogenic stressors to coral reef systems, these metrics will help identify the island ecosystems most exposed to both local and global stressors and identify systems that may be more resistant and resilient in the face of such stressors. This information is critical to managers tasked with formulating effective mitigating policies to help ensure the continued well-being of coral reef systems.

5A Remote sensing of reef environments
Tuesday 10 July, 0930, Sebel Mossman

Capability of the Sentinel 2 mission for coral reef mapping

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The Sentinel 2 mission, to be launched in 2013, offers continuity of service for the moderate resolution multispectral SPOT XS and Landsat Thematic Mapper series sensors that have been used extensively for reef mapping. This new sensor offers several design improvements that may lead to enhanced capability in coral reef mapping applications. In this study, modeling and simulated image analyses were conducted to evaluate the relative capability of the Sentinel 2 instrument design compared to SPOT-4 and Landsat ETM+, for mapping bathymetry and benthic composition. The analyses involved propagating noise and environmental uncertainties through a radiative transfer model inversion to quantify uncertainty in retrievable environmental parameters, such as depth, from each sensor. Results indicate that while variables related to reef 'health' such as coral mortality and algal cover cannot be mapped accurately by this class of instrument; Sentinel 2 does have an improved ability for discrimination of reef benthic composition over SPOT-4 and Landsat ETM+. The key enabling design factors are the narrowness of bands, increased spatial resolution and additional band at 443 nm. Instrument noise was a less significant factor. Rapid revisit times,

global coverage, and freely available data suggest the potential for analysing dynamics of coral reefs due to human impacts and natural processes.

5A Remote sensing of reef environments
Tuesday 10 July, 1215, Sebel Mossman

Coastal ocean radars applied to coral reef science and management

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Coastal ocean radars provide detailed surface current maps and wind directions in the coastal zone extending up to 150 km from the shore. Some types of HF radar also provide maps of wave heights. In the case of the Great Barrier Reef, this includes the continental shelf and some open water beyond. Detailed knowledge of the dynamics of the surface water opens the way for understanding much about connectivity and the movement of nutrients and pollution in the coastal ocean. Lagrangian tracking of buoyant particles can be achieved in the Great Barrier Reef Lagoon to an accuracy approaching 1 km (of error) per day of drift. This is a significant capability for search and rescue operations as well as reef science and management. A sequence of surface current maps has been shown to be useful for identifying areas where the currents are high enough to produce spontaneous turbulence throughout the water column. These areas are resilient against coral bleaching because the insolation heat is distributed through the water column rather than remaining at the surface. The wave height field produced by HF coastal ocean radars enables us to evaluate the amount of vertical mixing at the reef edge on the weather side, with the consequent distribution of thermal energy and nutrients. This paper is a review of the applications of coastal ocean radar data to the science and management of coral reefs.

5A Remote sensing of reef environments
Tuesday 10 July, 1115, Sebel Mossman

Spectral discrimination of coral species and habitats in Hong Kong

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In this study, the spectral data of four coral species of genera *Acropora*, *Goniopora*, *Pavona* and *Platygyra* were collected in the field and laboratory, plus that of coral habitats (sandy rock and sand), for spectral discrimination. All these lab coral species (at water surface) show two peaks at 600 nm and 710 nm unanimously. The reflectance values of field coral species (on the substratum) and habitats drop dramatically at 565 nm. The two distinctive spectral peaks of coral species are undetectable in local waters. Therefore, spectral bands at lower wavelength in the visible range, particularly in blue bands, are important in our study. For three of the lab coral species, the first derivatives of reflectance show peaks at a minimum of ~15 nm spectral separation. Hence, hyperspectral imagery is essential in the discrimination of coral species. The reflectance patterns and values of sand and sandstone differ greatly from coral species at water surface, but are much less discriminative underwater. These indicate the significant water column effect even in the region of the best water quality in Hong Kong's coastal waters.

5A Remote sensing of reef environments
P046

Ningaloo Reef: high resolution mapping achieved with hyperspectral, remotely-sensed data

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Effective management and monitoring of coral reef systems requires detailed baseline data about the distribution of marine habitats. Reefs with clear waters and complex geomorphology, such as Ningaloo Reef in Western Australia, naturally lend themselves to the application of optical remote sensing as a means of gathering information about benthic habitats, bathymetry, and adjacent coastal environments. Using HyMap hyperspectral data with 3.5m pixel resolution, we were able to retrieve very detailed information about the shallow water habitats of Ningaloo Reef (down to 20m depth). This large airborne survey was processed as mosaics of bottom reflectance data using all available spectral bands (up to 21) as well as 1st and 2nd derivatives. Data products include hierarchical thematic classification with up to 46 benthic cover classes as well as per-class probability and an objected-oriented classification which combined benthic classes, depth, slope, and aspect. From these, we established that over 50% of the substrate cover was composed of algae, and hard and soft coral cover made up 7% of the study area. The majority of the corals were a mix of different densities or morphologies of *Acropora* and 52% (875 ha) of the coral cover was located within the sanctuary zones of Ningaloo Marine Park. Through the use of operational pre-processing of the data and a semi-automatic image classification approach, we created seamless high resolution baseline maps for 3400 km^2 of the Ningaloo region, which are particularly suitable for ongoing monitoring and management.

5A Remote sensing of reef environments
Tuesday 10 July, 1500, Sebel Mossman

NOAA Coral Reef Watch's decision support system for coral reef management

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NOAA Coral Reef Watch (CRW) has been applying satellite remote sensing to monitor coral reef environments for more than a decade. To meet the ever-growing needs of coral reef managers and scientists for accurate and timely information on coral reef ecosystems, CRW has evolved from providing a limited number of satellite sea surface temperature (SST)-based tools, to implementing a decision support system (DSS), monitoring multiple satellite and model-based parameters. CRW is now developing a new-generation DSS, taking advantage of advances in satellite algorithms, availability of multi-satellites and multi-sensors, and model-based evaluations of observations and forecasts. CRW's new global SST product suite applies high-quality, 11 km satellite SST to monitor bleaching thermal stress more accurately, and is capable of providing regionally- and even reef-scale-focused products. With the availability of other satellite environmental parameters, such as surface light, and with advances in coral biological and physiological research, CRW has developed a Light Stress Damage product, combining light and heat stresses to more accurately monitor and predict coral bleaching and mortality. CRW has recently added satellite SST-based products to monitor and predict regional coral disease outbreaks and added multi-parameter products, such as Caribbean ocean acidification. Non-SST based satellite products, including ocean color-based products, are being planned for future development. Along with the model-based Seasonal Bleaching Outlook and Bleaching Weather Forecast, CRW has been operating an integrated DSS, utilizing satellite, model, and *in-situ* data, both near-real-time and historical, to help managers protect coral reefs in a changing climate.

5A Remote sensing of reef environments
Tuesday 10 July, 1630, Sebel Mossman

Next-generation high-resolution thermal stress monitoring for the Great Barrier Reef

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Remote sensing monitoring of oceanic thermal stress is undertaken routinely at various scales and across multiple spatial domains (regional to global) to predict the likelihood of coral bleaching events. These events are predicted to increase in severity and frequency under climate change, which underlines the importance of high-quality monitoring tools to lead response actions of reef management. ReefTemp is used on a daily to weekly basis year-round by the Great Barrier Reef Marine Park Authority (GBRMPA) to assess current temperature conditions over the reef at ~2km resolution. NOAA Coral Reef Watch (CRW) has provided global monitoring at ~50km for over a decade and more recently worked with regional collaborators on ~1 km monitoring products for the Florida and GBR regions. This project will streamline the efforts on the GBR by developing a next-generation of ReefTemp that updates the methodology of existing metrics (heating rate, degree heating days) and looks to incorporate CRW metrics (HotSpot, degree heating weeks). The products will be derived from multi-sensor composite SST data available through the Australian Integrated Marine Observing System (IMOS). Continuous SST monitoring provides researchers and stakeholders with tools to understand and better manage the complex interactions leading to coral bleaching. When bleaching conditions occur, these tools can be used to trigger bleaching response plans and support appropriate management decisions.

5A Remote sensing of reef environments
Monday 9 July, 1515, Sebel Mossman

AVHRR and MTSAT sea surface temperature products for the Australian region

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With support from the Integrated Marine Observing System (IMOS), the Bureau of Meteorology produces high-resolution satellite sea surface temperature (SST) products over the Australian region with additional information, including single pixel error estimates and quality flags, designed to suit a range of operational and research applications. The SST products include single and multi-orbit, as well as single and multi-sensor products. All products are in a CF-compliant netCDF format with extensive metadata and conform to the international Group for High Resolution SST (GHRSST: http://www.ghrsst.org) formats. These products can be accessed from the IMOS Ocean Portal (http://imos.aodn.org.au/webportal/) and the Australian Oceans Distributed Active Archive Centre (http://www.marine.csiro.au/remotesensing/imos/).
The ~1km spatial resolution of the AVHRR data enables localised heating events to be detected by using background temperature fields. The high temporal frequency of the hourly MTSAT data can

be used to describe the diurnal cycle and helps put the AVHRR observations into this context. The presentation will give a brief overview of each SST product including its strengths and weaknesses and research and operational applications, such as investigation of diurnal warming of the ocean surface over the Great Barrier Reef.

5A Remote sensing of reef environments
Monday 9 July, 1545, Sebel Mossman

A new bleaching product combining heat stress and light

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The NOAA Coral Reef Watch's global near-real-time coral bleaching operational monitoring product suite is extensively used by US and international resource managers, reef scientists, and the general public to monitor thermal stress and predict the onset, development, and severity of mass coral bleaching. However, its algorithms are based solely on satellite sea surface temperature (SST) observations. The new experimental Light Stress Damage (LSD) product is the first to combine satellite-derived light and SST data to monitor/predict coral stress that can lead to bleaching. The LSD product provides a relative measure of the effect of the combined light and thermal stress on the coral photo-system with values ranging between 0 and 1. Corals are expected to efficiently cope with light/temperature conditions when the LSD value is close to 1, but are expected to bleach when LSD value falls below a threshold (currently 0.4). Recovery is expected once the value moves back above the threshold. The LSD product is underpinned by a series of experiments that allowed the formulation of the relationships between the excessive excitation energy (EEE), relative potential quantum yield (Fv/Fm), change in SST, and differences in total daily photosynthetically active radiation (PAR). Several of these recent experiments will be discussed here. The LSD algorithm is then able to be formulated as a simple function of SST and PAR. It can be expressed as an index that mimics the reef-scale relative Fv/Fm.

5A Remote sensing of reef environments
Tuesday 10 July, 0945, Sebel Mossman

Autonomous systems for coral reef ocean acidification and ecosystem monitoring

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Coral reefs face increasing threats including ocean acidification and warming. To document coral reef ecosystem dynamics over space and time, we discuss incorporating autonomous systems, including autonomous surface vessels (ASVs) and unmanned aircraft systems (UAS), in reef monitoring studies. Autonomous systems can conduct transects past fixed sensors for inter-calibration, and can be controlled manually in real-time if features are detected, or use adaptive sampling software to undertake sampling to document spatial and temporal variability. Wave Glider ASVs use waves for propulsion and solar panels to power communications and sensors. Sensors demonstrated include meteorological systems, CTDs, thermistor chains, fluorometers, ADCPs, and an ocean acidification sensor. Surface cameras have been used to monitor ships for law enforcement, and underwater cameras and hydrophones can document reef use by turtles, sharks and whales. We describe the Wave Glider ocean acidification system, US demonstration projects, and options for incorporation into monitoring networks, including the US Integrated Ocean Observing System (IOOS), NOAA Integrated Coral Observing Network (ICON), and the Great Barrier Reef Integrated Marine Observing System (IMOS). UAS can include visible, infrared, hyperspectral, and SAR imaging capability, and can obtain heat, moisture, and momentum flux measurements. Previous manned aircraft experiments have mapped wave energy dissipation rate in a coral reef lagoon system - a critical parameter for assessing coral health - and this technology can be extended to unmanned platforms. UAS provide a safe and reliable means to measure topography, atmospheric conditions, air-sea interactions, and wave kinematics in coral reef environments.

5A Remote sensing of reef environments
Tuesday 10 July, 1030, Sebel Mossman

Remote sensing optically shallow waters of the Great Barrier Reef using MODIS imagery

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In shallow coral reef waters of the Great Barrier Reef (GBR), standard operational ocean color algorithms are often confounded where benthic reflectance is significant. In these situations, retrieved parameters such as chlorophyll-*a* (Chl*a*), total suspended solids (TSS), and inherent optical properties (IOPs) can be erroneous. As such, an operational robust algorithm for optically shallow regions of the GBR is required. A physics-based inversion model, the Hyperspectral Optimisation Process Exemplar (HOPE), has been developed for the retrieval of IOPs in optically shallow waters. The HOPE model solves for IOPs, bottom depth, and substrate reflectance albedo simultaneously via non-linear optimization. We have re-parameterised the HOPE model using high spatial resolution GBR-specific bottom depth and substrate reflectance data and applied it to moderate resolution imaging spectroradiometer (MODIS) imagery data. We present recent outcomes from an Australian Research Council funded collaborative project between Curtin University, the University of Queensland, the Australian Institute of Marine Science, NASA Ocean Biology Processing Group, and the University of Massachusetts, Boston. Challenges encountered in parameterising the model will also be discussed. In particular, appropriate spatial re-sampling of sub-pixel scale bathymetry data and substrate maps. We present field validation results which give an indication of the model's skill. In addition, we show the latest output results of the model applied to MODIS imagery, including maps of IOPs, Chl*a*, and euphotic zone depth (Zeu).

5A Remote sensing of reef environments
Monday 9 July, 1700, Sebel Mossman

Bidirectional reflectance of coral reef substrates corrected from above-water measurements

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In situ spectral reflectance measurements of substrates in a coral reef are often obtained by viewing a substrate at nadir. However, it is likely that off-nadir oblique viewing would obtain different spectral characteristics for most coral reef substrates and provide valuable information on structural properties. To understand the relationship between substrate structure and spectral response, this study examined the bidirectional reflectance distribution function (BRDF) of various growth-forms of hard corals and algae, as well as rock, rubble and sand. BRDF measurements were collected on Heron Island Reef, the Great Barrier Reef, using a visible and near-infrared (VNIR) spectroradiometer attached to a goniometer at five view zenith angles and three view azimuth angles. Spectral measurements were made above the water surface at low tide, so it was necessary to develop an algorithm to correct for water column and water surface effects that applies to off-nadir viewing over optically shallow waters. Uncorrected measurements for sand covered with benthic microalgae appeared to have BRDF effects, but when corrected showed an essentially diffuse spectral response. Corrected measurements for branching corals showed BRDF effects dependent on branch height and complexity. The results suggest that BRDF information can provide additional discriminating features for some coral reef substrates. The new correction technique can be used to remove water column effects in optically shallow waters.

5A Remote sensing of reef environments
Tuesday 10 July, 1245, Sebel Mossman

Mapping reef dynamics at multiple scales: Geomorphic-reef, Capricorn-Bunker Reefs

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Our ability to map the dynamics of coral reefs over 20+ years at regular intervals has been limited. Information is required at this scale to understand disturbance impacts and recovery, effectiveness of management activities, and to distinguish natural variability from human induced changes. We aimed to demonstrate ability of the Landsat sensors' global archive to map the dynamics of reef extent and geomorphic zones from 1987-2011 over several reefs in the southern Great Barrier Reef, Australia. These reefs were selected due to the extent of historic fieldwork and aerial photography. Landsat Thematic Mapper image data were acquired in a geometrically and radiometrically correct format. This provided an archive of at-sensor radiance data containing 70 images. The archive was subject to per-pixel classification to map geomorphic zones on the reef, based on previously defined classes. The resulting time-series of reef and geomorphic zonation maps enabled dynamic (animations), and static (trajectories of image pixels, and their resultant stability or dynamics) products to be assessed.Interpretation of the products enabled areas of stability and instability to be identified. Further work is required to define drivers of these changes, in relation to the dynamics of the sand-cay, coral-cover loss and gain due to engineering works, and reef-flat and lagoonal algal dynamics. These preliminary results indicate the utility and critical importance of building applications from long term global data sets.

5A Remote sensing of reef environments
Tuesday 10 July, 1545, Sebel Mossman

Optical coral reef monitoing system in Sasa Bay, Guam

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A moored, optical coral reef monitoring system (CRMS) has been operating in Sasa Bay, Guam in approximately 10m of water since January 2010. The purpose of the CRMS is to (1) collect seasonal background water clarity and natural coral fluorescence data in anticipation of future Navy construction projects nearby, and (2) provide a real-time alarm system during construction to warn of suspended sediment conditions that might threaten coral health. The monitoring system includes a set of two upward-looking, light, temperature and pressure sensors; one mounted approximately 3 m below the water surface and the other slightly above the coral reef. Optical data consist of irradiance measurements of PAR (400-700 nm), 443 nm, 510 nm, and 560 nm from which light attenuation values are calculated. Colour ratios from the two sensors can be used to determine whether turbidity is due to phytoplankton or suspended sediment. A third optical sensor is pointed at a coral plate (*Porites rus*) and collects radiance measurements of PAR, 665 nm, 683 nm and 710 nm. Zooxanthellae fluorescence (683 nm) is derived by subtracting calculated 683 nm reflected light from the total 683 nm signal. Data is internally recorded every half hour as well as transmitted by satellite, cell phone, or radio. Background seasonal field measurements will be presented. Natural fluorescence, as a gross measure of coral stress, will be discussed. Tribulations of satellite communications, boat strikes, fish bites, and biofouling will be shared.

5A Remote sensing of reef environments
Monday 9 July, 1730, Sebel Mossman

Mapping reef dynamics at multiple scales: patch-community, Heron Reef

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Coral Reefs are under continuous influence of the changing physical and biological processes that take place in the environment. Consequently, coral and algal communities can vary in abundance, diversity, and distribution. Remote sensing can be an ideal tool for monitoring such variation, which is needed for conserving and managing coral reefs. Object based high spatial resolution image analysis has been used successfully to map coral reefs at various multi spatial hierarchical scales; however, it has not been applied to detect changes in patch community composition of coral reefs. Here, we will demonstrate the application of object based high resolution image analysis to monitor variations in patch-communities on a coral reef over five years. From 2006-2011, annual high spatial resolution satellite imageries (Quickbird, Ikonos or Worldview2) were acquired, coinciding with georeferenced benthic photo transects on Heron Reef (30km^2) in the southern Great Barrier Reef, Australia. The satellite image data were corrected for radiometric and atmospheric distortions to at-surface reflectance. Georeferenced benthic photos were analysed for benthic cover composition and used for calibration and validation purposes. Hierarchical mapping from reef to geomorphic zone, then community scales, was completed using object based segmentation and semi-automated labelling through membership rules. Joint processing of the annual image and field data sets resulted in an assessment of the changes taking place in the benthic communities, with 70-90% accuracy for the individual maps. The study showed that object based image analysis can be used to map changes of benthic communities on coral reefs through time.

5A Remote sensing of reef environments
Monday 9 July, 1500, Sebel Mossman

Development of boat-based fluorescence imaging lidar for coral monitoring

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A boat-based coral observation system has been developed with the light detection and ranging (LIDAR) technique for large area coral monitoring. LIDAR is an optical active remote-sensing technique that uses a pulsed laser. In this study, a fluorescence imaging LIDAR system consisting of an ultraviolet (UV) pulsed laser with wavelength of 355 nm and a gated ICCD camera has been designed and tested. Most living reef-building corals have fluorescent proteins, and they emit blue to green fluorescence by UV excitation. In contrast, dead coral skeletons, sands, rocks, and algae show no blue-green fluorescence. The fluorescence LIDAR system harnesses this property. The seabed fluorescent images are recorded by shooting UV pulsed laser and receiving fluorescence by the gated ICCD camera synchronized with laser. Because exposure time can be very short, the sunlight background effect for the LIDAR image is suppressed, and it makes possible to detect weak UV excited fluorescence, even in the daytime. One can easily determine whether the coral is living or dead by checking the coral shape and fluorescent intensity of the fluorescent image. A performance evaluation test of the system was conducted at the testing basin, and both imaging and bathymetry performance for pseudo-coral targets were confirmed down to 30 m depth. Additionally, coral observation was conducted with a glass-bottom-boat at Taketomi Island, Okinawa, Japan. The information of live coral distribution along the boat track was successfully obtained from a survey area spanning 1.3 km in length, between 1-15 m in depth, and within 20 minutes of survey time.

5A Remote sensing of reef environments
Tuesday 10 July, 1730, Sebel Mossman

Benthic habitat mapping at Recife de Fora, Brazil: imagery and GIS

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Bahia hosts the largest and richest reef systems of the South Atlantic. Detailed bathymetry, high (spectral, spatial, and digital) resolution imagery, and a grid of diving stations spaced every 400 m (plus additional stations every 400 m along the reef edges) was used to assess the biogeology of reef composition. Sixty scuba-based ecological census sites were used for ground-truthing. Observations logged included substrate type, species or functional groups of Cnidaria (class Anthozoa and Hydrozoa), and functional groups of flora. A visual estimate of coverage areas was produced in a semi-quantitative hierarchy. High-definition videography and photography, as well as sediment and foraminifera sampling were also conducted. RGB triplets highlight WorldView 2's Coastal Blue Band capability of penetrating the water column, thereby assigning this band to the blue channel (e.g. RGB 321, 421, and 531), along with decorrelation stretches and PCA of the visible bands. The Quick Bird scene was used for comparison in RGB 321 and in the decorrelation stretch. Heads-up, on-screen photo-interpretation over a back-and-forth shifting of selected RGB triplets generated polygons in the GIS. These took into consideration the geomorphology interpreted from the bathymetry DEM and its derivatives (selected isobaths, hillshade, classified slope), as well as a generalized inverse distance weighed model of the predominant bottom type that was compiled from the scuba-based videography-and-field-book database stored in the GIS. The resulting classification scheme used three basic attributes to describe each mapped polygon. Coral cover is generally low and increases with water depth. The offshore geology is predominantly composed of smooth, compact sediment. Still, coral or accreted carbonate reef completely obscures the underlying geology.

5A Remote sensing of reef environments
P047

Next generation satellite tools: understanding environmental stress on coral reefs

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The University of Queensland, National Oceanic and Atmospheric Administration, Australian Institute of Marine Science, and Great Barrier Reef Marine Park Authority have been awarded a major grant under the Australian Research Council (ARC) Industry Linkage Grant Program. This is the largest ARC Linkage grant awarded, with a total value of $8.2 million over five-years (53% cash, 47% in-kind). The project will develop and expand the ability of satellite algorithms to predict impacts of coral stress. Specifically, it seeks to develop a suite of satellite-based algorithms that vastly improve predictions of coral bleaching onset, severity, recovery, mortality, and ecosystem impact. Satellite algorithms are built upon specific knowledge of interactions between the environment and coral physiological responses. Significant gaps exist in this knowledge, including unexplained variances in predicting thermal stress, poorly defined understanding of coral stress in the field, and limited understanding of ecosystem outcomes associated with bleaching. This project seeks to fill aspects of these knowledge gaps to improve the ability to produce management-relevant satellite algorithms. There are three phases to this project: 1) Conduct microcosm experiments on a number of coral species from multiple sites to underpin satellite algorithms. 2) Develop a network of small *in situ* pulse amplitude modulated (PAM) flourometers to close the gap between the results from microcosm experiments and field observations, and to validate the satellite algorithms. 3) Conduct microcosm experiments under a number of climate scenarios to understand climate change impacts on various aspects of the environment/physiological relationships obtained in (1).

5A Remote sensing of reef environments
Tuesday 10 July, 1000, Sebel Mossman

Ocean colour remote sensing of the Great Barrier Reef waters

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Algorithms have been developed to measure total suspended solids, total Chlorophyll-a, and dissolved organic carbon (DOC) in optically deep Great Barrier Reef (GBR) waters from the near-daily imagery provided by the moderate resolution imaging spectroradiometer sensors (MODIS). The novel algorithm development, data collection methodology, and modelling techniques played a significant part in the performance of the algorithms, so are documented with sufficient detail to promote scientific transparency, independent assessment, and ultimately the improvement of ocean colour

remote sensing in Australian waters. Single-overpass imagery is presented as an additional visual assessment of the algorithms. Potential limitations are discussed to provide a way forward for future studies in GBR waters.

5A Remote sensing of reef environments
Monday 9 July, 1630, Sebel Mossman

Enhanced satellite-remote sensing for coral reef management: the next decade

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For the past decade, remote sensing products have been provided by NOAA's Coral Reef Watch (CRW) that uses satellite-derived sea surface temperature (SST) measurements to inform coral reef managers, scientists, and the public. These products, tailored primarily for managers, have become well-accepted as they provide a cost-effective means of conducting near-real-time monitoring of changes in SSTs that impact coral reef ecosystems over broad spatial scales. Recently enhanced and future operational remote sensing products that collect SST data as well as additional environmental variables are being developed at NOAA's Center for Satellite Applications and Research (STAR). Non-SST-based monitoring products include: i) ocean color to track land-based sources of pollution, ii) synthetic aperture radar to detect oil spills and possibly coral spawning events, iii) insolation to measure coral photosystem health, iv) ocean surface vector winds to model biological connectivity via wind currents, and v) satellite altimetry to measure and track long-term trends in sea-level rise and short-term storm surge and significant wave heights. These products hold great promise for the data-rich and broad spatial perspective they provide, and for improving the quality and effectiveness of coral reef management of coastal resources. This new report describes CRW's recent and forthcoming remote sensing products and demonstrates their applicability to coral reef management priorities, including the NOAA Coral Reef Conservation Program Goals & Objectives. Furthermore, it uses these products as a template for more wide-reaching global usage.

5A Remote sensing of reef environments
Tuesday 10 July, 1015, Sebel Mossman

Application of an integrated technique for comprehensive seafloor mapping

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Here, we demonstrate the application of an integrated technique used to investigate seafloor composition. The integrated technique includes side-scan sonar, single-beam echo sounder, and a video camera slide. A 1.07km^2 area off Wang-An, Pen-Hu, Taiwan, was selected for this investigation. Water depth in this area ranges from 4-25 m (averaging 16m). The depth in about half of the area ranges from 14-17m. Two topographic ridges exist; one is in the northern sector, and the other, which covers a much larger area, is in the southern sector. Platy shaped coral reefs are located on the ridges at both the northern and southern sectors. However, the outer appearance and dimensions are much more prominent for reefs at the northern sector than at the southern sector. This integrative technique creates a comprehensive map of the seafloor, and is specifically useful for detecting and mapping coral reef distributions.

5A Remote sensing of reef environments
Tuesday 10 July, 1530, Sebel Mossman

SeaWiFS sattelite-derived data on Chl algal standing stock anomaly, and related nutrient sources on the Queensland continental shelf

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Studies suggest that inshore parts of the Great Barrier Reef (GBR) lagoon are or will soon become eutrophic as a result of anthropogenic nutrient enrichment. GBR phytoplankton dynamics generally display a seasonal pattern, with algal standing stock (Chl) at an annual maximum during the summer wet season. Observations suggest that fluvial discharge is a primary source of nutrients for algal growth in this region, although upwelling, biological nitrogen fixation, and rainfall are also sources of nutrients. Aeolian mineral dust deposition is thought to be a critical source of dissolved iron (dFe) for phytoplankton growth in some oceanic regions. However, research on aeolian dust delivery of nutrients to GBR waters has been very limited in comparison with fluvial nutrients. In this study, satellite (SeaWiFS) data on Chl in Queensland continental shelf waters is examined and related to both fluvial and aeolian nutrient sources. A weekly climatology of Chl was derived from the 8 day binned Chl-*a* for the whole SeaWiFS mission. Weekly Chl-*a* anomalies were computed and periods of high positive anomaly (indicating a bloom event) were correlated with fluvial discharge or dust storm events. Results indicate high Chl positive anomalies inshore and near river mouths during flood periods due to fluvial nutrients and sediment. Significant positive Chl anomalies extended offshore in the southern GBR lagoon and southern Fraser Island waters during drought periods, particularly in October and November of 2002-2005 and 2009. This may reflect the impact of dust-derived nutrients from dust storm events in eastern Australia.

5A Remote sensing of reef environments
P048

High-resolution thermal stress indices for regional coral bleaching forecasts

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Temperature-induced coral bleaching is thought to be one of the most important environmental parameters responsible for physiological stress of coral reef organisms. A collaborative effort between NASA, NOAA, and University of South Florida seeks solutions to enhance the NOAA's Coral Reef Watch (CRW) sea surface temperature data products.This program uses operational, near-real-time night time Advanced Very High Resolution Radiometer (AVHRR) sea surface temperature (SST) data to produce SST climatologies and various thermal stress indices that include SST anomalies, HotSpots, and Degree Heating Weeks.Similar indices will be generated with higher -resolution AVHRR and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery by using data at 1 and 4 km spatial resolutions. Anomalously cold temperatures can also lead to significant stress and cause widespread mortality in coral reefs, such as that which occurred in the Florida Keys during January 2010. This project also studies this test case to develop 1 km spatial resolution cold-stress indices. *In situ* data collected around the Florida Keys in January 2010 is used to validate prototype products, together with efforts to discriminate cold water from clouds. Coral cover and bleaching data for the Florida Reef Tract were obtained from the Coral Reef Evaluation and Monitoring Program (CREMP), Reefbase and Bleach Watch. These data are used to test the warm and cold high-resolution stress indices and to assess significant bleaching events.

5A Remote sensing of reef environments
Monday 9 July, 1530, Sebel Mossman

Coral reefs of Boat Island: a hyperspectral remote sensing perspective

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In the absence of *in situ* data, satellite remote sensing is the only way to map coral reef features synoptically. Among the various remote sensing options available today to discriminate between healthy and unhealthy corals, hyperspectral remote sensing is superior by virtue of its spectral capabilities, while high spatial resolution remains a necessary condition to spatially resolve finer morphological features. Given that high spatial resolution data is better than the Landsat equivalent of 30m spatial resolution, the discrimination capability of end-members of satellite data is dependent on the efficacy of the correction for atmospheric effects and the intervening water-column. Here, a coupled ocean atmospheric correction (COART) was applied over the EO-1 Hyperion data acquired over Boat Island, located in the Andaman and Nicobar island groups. The resulting reflectances were further analyzed using spectral derivative analysis to discriminate between unhealthy and healthy coral pixels, and to compared against the *in situ* data acquired using transect analysis. Our findings confirm that Hyperion has sufficient discrimination capabilities and can further be improved using coupled radiative transfer models.

5A Remote sensing of reef environments
Tuesday 10 July, 1200, Sebel Mossman

Spatio-temporal patterns of water clarity on the Great Barrier Reef

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Detecting changes in the transparency of the water column is critical for understanding the responses of marine organisms, e.g. corals, to light availability. Long-term patterns in water transparency determine geographical and depth distributions while acute reductions cause short-term stress, potentially mortality and may increase the organisms' vulnerability to other environmental stressors. Here, we investigate the optimal, available operational algorithm for light attenuation through the water column across the scale of the GBR ecosystem. We implement and test a quasi-analytical algorithm to determine photic depth in GBR waters, and match regional Secchi Depth data to MODIS Aqua (2002-present) and SeaWiFS satellite data (1997-present). The results of the *in situ* Secchi / satellite data matchup show a simple bias offset between the *in situ* and satellite retrievals. We regress the in-situ data against the 10% photic depth level and use a Type II linear regression of log-transformed satellite and *in situ* data to adjust the match in satellite data retrievals. We implement a GBR-validated Secchi depth algorithm and generate satellite time series across the scale of the GBR ecosystem. We apply an Empirical Orthogonal Function Analysis to the dataset to determine the dominant modes of variation and compare these with the sea surface temperature dynamics. We identify the physical drivers that influence the spatio-temporal patterns of water clarity across the GBR ecosystem as seasonal variability in terrestrial

inputs, regional patterns of upwelling, and mixing and exchange with the Coral Sea.

5A Remote sensing of reef environments
Monday 9 July, 1645, Sebel Mossman

Utilizing GIS in coral reef conservation

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A Geographic Information System (GIS) is a powerful, interactive, and versatile tool that can promote and aid in coral reef conservation and marine protected area management. The Khaled bin Sultan Living Oceans Foundation utilizes GIS in order to visualize coral reef ecosystems by compiling information at a regional scale that is perceived to be relevant to the concept of resilience. This involves overlaying various spatial data, such as satellite imagery, benthic habitat maps, sea surface temperatures, fisheries information, and field survey locations, with points for specific locations that compile all available resilience data. Geographic Information Systems are not just a one-application product, but the data within a GIS can be disseminated through many outlets, such as being displayed in an interactive, queryable, web-based GIS application or in an atlas. From 2006-2009, over 7,300km^2 of the Saudi Arabian Red Sea coastline was mapped by the Foundation and its partners using very high-resolution QuickBird imagery to generate benthic habitat and bathymetric maps. These data were overlaid with the imagery and exported to create an atlas of the Saudi Arabian Red Sea coastline that will be of great value to marine resource managers in Saudi Arabia, in addition to being delivered as an interactive GIS package. The Foundation has been able to generate vast geographic information over a large area of the Red Sea, in a very short time and at reasonable cost, thereby enabling Saudi Arabian marine resource managers to understand the full extent of their Red Sea reef tract.

5A Remote sensing of reef environments
Tuesday 10 July, 1715, Sebel Mossman

Hilo Bay revisited: airborne lidar bathymetry and hyperspectral image fusion

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At ICRS 2008, we presented state-of-the-art airborne lidar bathymetry and hyperspectral image fusion using data collected near Hilo, Hawaii, as an example. The data were collected concurrently in 2007 using the U.S. Naval Oceanographic Office's Compact Hydrographic Airborne Rapid Total Survey System in support of US Army Corps of Engineers coastal mapping requirements. Here, we update the techniques for airborne lidar bathymetry and hyperspectral imagery pre-processing, image fusion techniques, and classification of the final bottom image products. Improvements in processing lidar bottom reflectance, a light analogue to sidescan sonar, gave better results in shallow water (0-6 m range) where lidar surface and bottom returns merge, making estimates of attenuation problematic. A new spectral optimization technique was developed for hyperspectral imagery that solves for atmospheric and oceanographic constituents in a decomposition solution, using depth derived from the bathymetric lidar data as a fixed constraint. Two approaches to image fusion led to improved bottom classification results. In the first, texture and neighborhood characteristics extracted from the lidar bathymetry and reflectance are integrated with hyperspectral image spectra in a feature analysis process to determine which contain the most relevant information to develop a benthic classification product. In the second, bottom segmentation images from lidar-only and hyperspectral-only techniques are combined in a feature-level, statistically-driven approach to data fusion, yielding a final classification product with higher accuracy than its inputs. These new techniques are demonstrated at the Hilo site and compared to existing maps of the area.

5A Remote sensing of reef environments
Tuesday 10 July, 1230, Sebel Mossman

Mapping of coral reef habitats using WorldView-2 in Abrolhos, Brazil

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Regional monitoring of coral reef habitat change is important for global change studies. For this purpose, remote sensing is a useful tool providing a synoptic coverage, with good spatial and temporal resolution. The WorldView-2 orbital sensor is a high spatial resolution (2 m) sensor, which has also a higher spectral resolution compared to other orbital sensors with similar spatial characteristics (8 multi-spectral bands). Despite its great potential for target discrimination, coral reef mapping is still underexplored. Here, we aimed to perform an exploratory analysis to discern the capabilities of the WorldView-2 orbital sensor for coral reef habitat mapping in a shallow reef of the Abrolhos Bank, Brazil. The Abrolhos coral reef bank is a major biodiversity hot spot in the South Atlantic Ocean and hosts some endemic Cnidaria species. We used a WorldView-2 image collected on Jan/25/2010. Digital numbers were converted to surface reflectance. Image segmentation was done followed by digital classification using an unsupervised ISOSEG algorithm (99.9% significance). Spectral classes were assigned to 11 thematic classes: deep water, shallow water, seagrass, sand, carbonatic platform, Zoanthid coral, *Sargassum* sp., deep substrate, and 3 types of mixed substrate. Using a simple methodology,

WorldView-2 produced a more detailed map than other previous maps in the area obtained from IKONOS and Landsat imagery, indicating a better performance with more information of the benthic habitat. Further work concerning field validation of this classification is needed, and will be held next summer.

5A Remote sensing of reef environments
P049

5B Sensor networks and their applications

NOAA SeaDroid: low-cost, real-time water temperature logging

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SeaDroid is a NOAA HPCC funded investigation into using smartphones to provide both water temperature data logging and near real-time data transmission. With the advent of powerful, highly programmable 'smartphones', we are customizing an Android handset to interface to a temperature sensor for data logging and then transmit that data wirelessly. While simple data loggers are low cost, they have no transmission capability, meaning important environmental events cannot be responded to or investigated. Real-time monitoring systems can be too expensive to meet smaller project budgets. Perceiving that there is a middle ground between these limitations that can be catered to by a customized, protectively-packaged cell phone handset, we are developing drivers and application software to provide payload services. Our goal is to allow the phone to act as an intelligent receiver of sensor data and also as data transmitter to a remote database across the phone network. The intended deployment environment for the prototype is mounting on a simple fixed 'stick' in the substrate and thus would be appropriate for near-coastal shallow water applications, e.g., coral reef lagoons. We will report on the project outline and progress, covering details such as the evaluation and acquisition of Android handsets and associated hardware for marine environment use; development of a custom firmware image for minimal power use; device driver development; development of software for data logging in permanent storage on-board and synchronization with remote systems; and deployment of our prototype in a marine environment.

5B Sensor networks & their applications
Wednesday 11 July, 1200, Sebel Mossman

Effect of environmental noise on detection probability of acoustic tags

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Acoustic telemetry is an important tool for studying the movement patterns, behavior, and site fidelity of marine organisms; however, its application is challenged in coral reef environments where complex topography and intense environmental noise interferes with the acoustic signal. Therefore, it is particularly critical in coral reef telemetry studies to first conduct a long term range test, a tool that provides information about the variability and periodicity of the transmitter detection range and the detection probability. A one month range test of a coded telemetric system was conducted prior to a large scale tagging project investigating the movement of 400 fishes from 25 species on outer coral reefs in the central Red Sea. During this long term range test we determined the effect of the following factors on transmitter detection efficiency: distance from receiver, time of day, depth, wind, current, and temperature. The experiment showed that biological noise is likely to be responsible for a diel pattern of -on average- twice as many detections during the day as during the night. Detection probability is also heavily influenced by wind-induced environmental noise and the location of the acoustic sensor within the reef structure. Understanding the effect of environmental factors on transmitter detection probability allowed us to design a more effective receiver array for the large-scale tagging study, and will allow us to correct for changes in environmental variables when analyzing the fish movement data.

5B Sensor networks & their applications
Wednesday 11 July, 1130, Sebel Mossman

The dataturbine android buoy controller for coral reef monitoring

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The OSDT-Android Sensor Pod is a next-generation smart buoy controller that we are developing for applications in coral reef ecology. It combines the open-source data turbine (OSDT) streaming data middleware with the Android platform to provide a robust, scalable, embedded computing and communications platform for distributed sensor networks. This project involves a combination of software and hardware developments together with field deployments for studying physio-chemical environmental variation in the context of ongoing ocean acidification. As part of the project, we ported the OSDT middleware to the Android platform and developed new software

for configuring and managing real-time embedded applications. The OSDT-Android controller communicates with sensors through the Sea-Bird Inductive Modem interface and manages sensor interfaces, data acquisition, on-board processing, and data transmission over multiple types of radios, including Iridium satellite, cellular, Bluetooth, and long-distance wireless. Developed in Java, the OSDT sensor pod can manage a local constellation of sensors and communicates with other OSDT-enabled platforms. It can be readily updated to incorporate new software modules, and dynamically reconfigured to schedule these modules to control sensor operations and communications. It is designed to support on-platform event detection and real-time control, and includes software for scheduling sensor operations and communications. It has been tested with a variety of sensors for measuring environmental variation, including pH, pCO_2, dissolved oxygen, temperature, and pressure. Initial field deployment of the OSDT-Android Sensor Pod is occurring at the Moorea Coral Reef Long Term Ecological Research (LTER) site in French Polynesia.

5B Sensor networks & their applications
Wednesday 11 July, 1145, Sebel Mossman

Wireless architectures for coral reef environmental monitoring

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Researchers at the National Oceanic and Atmospheric Administration's Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami, FL, USA, and at the Australian Institute of Marine Science (AIMS), Townsville, Qld, have over the past decade developed wireless architectures for transmitting meteorological and oceanographic data in near real time from coral reef ecosystems in the Caribbean and Indo-Pacific to agencies and researchers. These efforts are made to establish trends in environmental conditions, and for purposes of ecosystem modeling (as 'ecoforecasts'). The architectures utilized (and planned) are described, and include the use of a Geostationary Operational Environmental Satellite, radio transceiver, wireless digital cellular modem, mobile wireless hotspot, and Android phone. Each architecture is reviewed for advantages and disadvantages, and recommendations are made for specific support structures (e.g., buoy, pylon, pier, etc.), as well as for the level of anticipated field support. Two proposed architectures are described: 1) AOML's newly expanding Coral Reef Early Warning System network in the Caribbean, which is being developed in collaboration with the Florida Institute of Oceanography and the Caribbean Community Climate Change Center in Belize; and, 2) a prototype network extension to the AIMS Great Barrier Reef Ocean Observing System.

5B Sensor networks & their applications
Wednesday 11 July, 1115, Sebel Mossman

Sensor networks applications for reefs at Racha Island, Thailand

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Remote coral reef islands present a series of challenges for deploying coral reef sensor networks. This paper presents the experience of deploying sensor networks at Racha Yai Island in southern Thailand. Racha Yai Island is far offshore of Phuket and so the island suffers very little from sediment loads from Phuket. It is one of the most popular tourist sites for SCUBA/snorkel activities. It presents a logistically challenging environment for both researchers and instruments because it is characterized by large but shallow bays, storms, and occasional power and internet outages. The island's coral ecosystem consists of hard and soft corals with many marine resources. So far, serious impacts on the ecosystem have included the 2004 tsunami, a major bleaching event in May 2010, and heavy tourist traffic from both snorkelling and SCUBA. In response to the bleaching event, a sensor network was installed in early 2011 to provide future real time information about events. The system installed includes an underwater camera, two shore cameras, a CTD, multiple HOBO temp/light sensors, G sensors, and two Davis weather stations. Data are streamed through multiple DataTurbine servers and put into in-house data servers in several formats after cleaning with data quality tests including statistical ones. The data are then available on-line through a public outreach site. This site is part of the Coral Reef Environmental Observatory Network (CREON) and is under consideration for inclusion in the International Long Term Ecological Research (ILTER) Network.

5B Sensor networks & their applications
Wednesday 11 July, 1215, Sebel Mossman

CREON: integrating disparate sources of remote coral reef sensor data

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The Coral Reef Ecological Observatory Network (CREON) is a grass-roots, self-assembled group of coral reef scientists and engineers to advance the understanding of coral reef dynamics by facilitating the development of practical environmental sensor networks. One of the goals of the group is to develop integrated data products and outcomes from the various CREON sites. This paper presents an overview of the use of cloud computing based data architectures, such as Pachube, to deliver integrated data outcomes using a range of disparate real-time data from each site. The outputs include simple event detection systems with alerts being delivered to social network sites such as 'Twitter'. This allows the multitude of collected data to be reduced to a small number of interesting or meaningful events. The system is being used to identify local events that may have a global context and as a tool for monitoring these sites. The group also has developed a suite of technologies that lowers the cost of entry for deploying sensor networks on coral reefs in areas poorly or under sampled. A second goal of CREON is to include a greater range of real-time coral reef sensor data through the use of an open, common cloud based computing system. This may include providing technology transfer to new sites and groups that are not currently engaged, especially those in areas that do not currently have a sensor network.

5B Sensor networks & their applications
Wednesday 11 July, 1230, Sebel Mossman

Spectrophotometric measurements of seawater carbonate ion concentrations and saturation states

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Since the industrial revolution, ocean acidification has decreased the concentration of carbonate ions in seawater, adversely affecting calcification rates. Carbonate ion concentrations and carbonate saturation states are conventionally calculated from temperature, salinity, and two measured CO_2 system parameters. Recently, procedures have been developed for direct measurement of carbonate ion concentrations in seawater by observations of Pb(II) spectra in the ultraviolet. Field-testing of this carbonate measurement procedure was undertaken during hydrographic surveys along the west coast of the United States from Washington State to southern California near the end of the upwelling season in August-September 2011 onboard the Wecoma. Past surveys have shown that seawater is undersaturated with respect to aragonite along large portions of the continental shelf in this region. In addition to carbonate, other CO_2 system parameters measured along the transect were pH, DIC, and TA. This presentation describes comparisons between carbonate ion concentration measurements determined directly by UV spectroscopy, and carbonate ion concentrations that were calculated using paired combinations of pH, DIC, TA, and pCO_2. In addition, this presentation will describe recent progress on development of an in-situ instrument capable of direct measurements of carbonate ion concentrations and saturation states in seawater.

5B Sensor networks & their applications
Wednesday 11 July, 1245, Sebel Mossman

5C Genomics & proteomics as tools for detecting sub-lethal stress

Proteomic response of *Stylophora pistillata* endosymbionts to moderate 'bleaching' stress

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We present the proteomic response of *Symbiodinium* sp. endosymbionts from the coral *Stylophora pistillata* of the central Great Barrier Reef to moderate conditions of thermal 'bleaching' stress, with and without trace metal limitation. Using quantitative high throughput proteomics, we identified 8098 MS/MS events relating to individual peptides from the endosymbiont-enriched fraction. These included 109 peptides meeting stringent criteria for quantification of which only 26 showed significant change in our experimental treatments; 12/26 increased expression in response to thermal stress with little difference affected by iron limitation. Surprisingly, there were no significant increase in antioxidant or heat stress proteins; those induced to higher expression were generally involved in protein biosynthesis. An outstanding exception was a massive 114-fold increase of a viral replication protein indicating that thermal stress may

substantially increase viral load and thereby contribute to the aetiology of coral bleaching and disease. In the absence of a sequenced genome for *Symbiodinium* or other dinoflagellates, this proteome reveals a plethora of proteins potentially involved in microbial-host interactions. This includes photosystem proteins, DNA repair enzymes, antioxidant enzymes, metabolic redox enzymes, heat shock proteins, globin hemoproteins, proteins of nitrogen fixation and metabolism, and a wide range of viral proteins associated with these endosymbiont-enriched samples. Also present were 21 unusual peptide/protein toxins thought to originate from either microbial consorts or contamination by coral nematocysts. Of particular interest are the proteins of apoptosis, vesicular transport and endo/exocytosis, which we shall discuss in the context with processes of coral bleaching.

5C Genomics & proteomics as tools for detecting sub-lethal stress
Wednesday 11 July, 1030, MR3

Characterizing transcriptional responses in corals exhibiting Caribbean Yellow Band Disease

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Here, we characterize the expression of Caribbean Yellow Band Disease (CYBD) at the level of gene transcription. Colonies of *Montastrea faveolata* were chosen based on the visual conditions of healthy (no visible signs of disease), diseased (visual discoloration), or healthy portions of a diseased colony. A small suite of genes (immunoglobulin, cytochrome oxidase, fibronectin, superoxide dismutase, and ubiquitin oxidase) were used to develop transcription profiles for each condition investigated. Transcription profiles were characterized using quantitative real-time PCR (qPCR) to compare relative expression levels for the five genes of interest (GOI). Preliminary results suggest there are quantifiable differences in expression levels of GOIs between healthy portions of diseased corals, diseased portions of diseased corals, and healthy coral colonies.

5C Genomics & proteomics as tools for detecting sub-lethal stress
Wednesday 11 July, 1000, MR3

How corals can tell us what's ailing them

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With coral reefs in decline at the global level, there is an urgent need to move away from simply documenting their demise and towards diagnosing and treating the underlying causes. With multiple stressors acting synergistically on corals and reef ecosystems, a scientific, evidence-based approach becomes critical for determining appropriate actions and assessing their effectiveness in real time rather than years to decades. Techniques and approaches routinely used in human medicine to assess and treat illnesses can also be applied to corals and other key reef organisms within a diagnostic framework. Specifically, molecular biomarkers of exposure to stressors can be used to identify key cause-and-effect relationships as well as determine the effectiveness of mitigation efforts. For example, xenobiotic metabolizing enzyme profiles can be used to identify specific toxicant exposure in corals, prior to outright mortality, when responses may still be effective in preventing loss of individuals or populations. Other molecular biomarkers of value include those that identify DNA damage, the ability of organisms to properly repair and metabolize proteins, and those that indicate oxidative stress. Three techniques, enzyme-linked immunosorbant assays (ELISA), fluorescent microscopy assays, and enzyme kinetic assays, are being used to determine the primary and synergistic stressors affecting corals in the field. These techniques are paired with controlled laboratory exposures to calculate thresholds beyond which corals cannot recover. Our data also demonstrate that factors such as reproductive state can influence the activities of key enzymes and that a holistic approach is needed to address coral reef resilience to multiple stressors.

5C Genomics & proteomics as tools for detecting sub-lethal stress
Wednesday 11 July, 0930, MR3

Coral-algal transcriptomics as a tool for predicting impacts of environmental change

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Coral reefs are the most diverse marine ecosystems, providing habitat for an estimated 25% of marine organisms. Within the foundation of this ecosystem, reef-building corals form mutualistic symbioses with unicellular photosynthetic dinoflagellates of the genus *Symbiodinium*. The stability of coral-algal partnerships is dependent on environmental variability, with the majority of symbioses being very susceptible to changes in temperature. Exposure of coral-algal symbioses to thermal stress can lead to the loss of symbionts from the coral host's tissues and bleaching. We have investigated changes in gene expression within *Symbiodinium* and found distinct responses

to thermal stress for the newly discovered Cytochrome P450 genes as well as the heat shock proteins (Hsp) and also hemoglobin-like genes. Different gene expression patterns observed for Hsp70 and Hsp90 suggests diverse role of these molecular chaperones during heat stress response. From transcriptomic analyses of the coral holobiont exposed to various ecological scenarios that included heat and nutrient stress, we show new insights into mechanisms of stress response including discovery of new stress biomarkers. As the susceptibility of coral to stress and bleaching may vary depending on the clade or type of algal symbionts they harbour, we applied novel genomic tools to assess genetic similarity and diversity among four phylogenetically diverse dinoflagellate clades commonly associated with corals. These results will provide important insight into the potential genetic responses and consequently mechanisms of reef-building corals and their symbionts to respond to future changes in climate.

5C Genomics & proteomics as tools for detecting sub-lethal stress
Wednesday 11 July, 0945, MR3

Xenobiotic metabolizing enzymes: tools for coral reef conservation

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Globally, the continued deterioration of coral reefs requires us to go beyond ecological monitoring and to discover, define, and utilize appropriate biomarkers of coral health. Such biomarkers allow for early detection of coral stress caused by sub-lethal exposures to stressors that may not be apparent through general observation. Xenobiotic metabolizing enzymes (XMEs, detoxification enzymes), present a set of such biomarkers. Since it is known that the protective activities of detoxification enzymes can change under environmental and/or genetic stresses, these enzymes may be used as diagnostic tools. However, in order to utilize them appropriately and distinguish alterations resulting from stress, the normal physiological functions as well as intra-individual and population variability of XME's in corals must be defined. Our research has analyzed several key XME's in healthy adult colonies of *Pocillopora damicornis* over its lunar reproductive and physiological cycle to determine baseline enzyme activities and expression, inclusive of normal fluctuations. Because these enzymes naturally fluctuate over the reproductive cycle, it is essential to understand the natural magnitude of these changes so that the influence of life history can be discounted from the influence of exogenous stressors. We found several XME's that may be useful as biomarkers for endocrine disruption, including UDP-glucuronosyltransferase and sulfotransferase, and others that may be more suitable as indicators of chemical toxicity exposure: glutathione-S-transferase, β-glucuronidase and steroid sulfatase. Such biomarkers can support evaluation of preventative measures used to mitigate toxicity to existing reefs prior to outright mortality.

5C Genomics & proteomics as tools for detecting sub-lethal stress
Wednesday 11 July, 1035, MR3

Analysis of Hsp60 expression in corals subjected to different abiotic and biotic stresses

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Heat shock proteins (Hsps) are a highly conserved family of stress response proteins which represent one of the most important defence mechanisms of all organisms and a commonly used biomarker in coral health assessment. They function primarily as molecular chaperones, preventing protein aggregation, facilitating proper protein folding and complex assembly. Hsps are expressed at low levels under normal physiological conditions, but their expression is up regulated as a consequence of exposure to a wide variety of stressors that perturb cellular protein structure. The effects of both abiotic and biotic stress factors on the expression and modulation of 60-kDa heat shock proteins (Hsp60) were examined in various scleractinian coral species. In particular, as abiotic stresses we tested the effects of the high (28-36°C) and low (21-16°C) temperatures and of the extreme levels of salinity (from 15- 45‰) through short-term and long-term stress experiments in controlled aquarium tanks, followed by morphological observations of the colonies, proteins extraction, and Western blot analysis. Among the biotic stresses we tested in the natural habitat of Maghoodhoo Island lagoon (Maldives), were the effects of biological interactions involved in coral reef degradation such as coral diseases, (e.g., skeleton eroding band caused by the protozoan *Halofolliculina corallasia*) and the algal overgrowth. The results show that the different coral species display a different modulation of Hsps, and confirm that they are involved in the mechanisms of cellular response to physical stresses, and provide evidence that their expression is also modified by biological stress factors.

5C Genomics & proteomics as tools for detecting sub-lethal stress
Wednesday 11 July, 1015, MR3

5D Robots & machine learning techniques aiding coral reef science

Automated coral reef image annotation using computer vision

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Large sets of quantitative benthic images are routinely acquired as part of coral reef surveys. From these images, population statistics for benthic taxa can be estimated using random point sampling. This requires an expert to classify the substrate beneath randomly distributed points, typically 10 - 200, overlaid on each image. In recent years, several automated image acquisition techniques, such as AUV and tow-surveys, have been deployed, which greatly increase the number of images acquired. Meanwhile, the annotation work remains manual, often causing the annotation effort to involve considerably more time than the image acquisition. We address this issue by developing an automated image classification system based on recent advances in machine learning and computer vision. The system is trained on the color and textural characteristics, extracted at multiple scales, of patches surrounding image points previously identified by an expert. In operation, given a new image, the program proposes classifications based on these references for rapid examination and approval by the human operator. Once approved, the new data are used to further improve the fidelity of the automated classifier. This 'human in the loop' process proceeds toward faster and more accurate automated annotation for subsequent images in the data set. Experiments on the NSF Moorea Coral Reef Long Term Ecological Research site (MCR-LTER) demonstrate consistent and accurate classification over several years and thousands of images. Other Pacific and Caribbean datasets are used to evaluate method generalization. Finally, we present a web based platform, CoralNet, for the annotation and sharing of images.

5D Robots & machine learning techniques aiding coral reef science science
Monday 9 July, 1200, Sebel Mossman

Interpreting benthic stereo imagery using appearance and 3D structure

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Benthic mapping programs that collect optical imagery produce vast, rapidly growing volumes of data. The onerous, time-consuming nature of human data interpretation makes detailed classification of complete datasets infeasible. Consequently, automated techniques are required for efficient and effective analysis. Machine learning algorithms are useful for image-based interpretation and can generally be broken into supervised classification and unsupervised clustering techniques. Supervised classification techniques generally still require substantial human input in the form of human-labelled examples. Unsupervised clustering techniques do not require labelled examples for training; however, without a human in the loop, there are no guarantees that the clusters will represent semantically relevant information. Unsupervised techniques are useful for examining patterns and structure in the data and provide sensible initialisation for active learning. Active learning can be used to query and learn from a human oracle in a way that maximises the usefulness of the labels, while minimising the amount of human effort. Feature descriptors are an important consideration for any machine learning algorithm and need to be selected such that they capture the semantic content of the images. Our approach uses stereo imagery to interpret the data based on visual appearance and 3D structure at multiple scales to distinguish habitat types. Terrain complexity features such as rugosity and slope at multiple scales are combined with image appearance features such as colour and texture. We have implemented a pool-based active learning framework with pre-clustering and the results show higher classification accuracy with lower human labelling effort.

5D Robots & machine learning techniques aiding coral reef science science
Monday 9 July, 1145, Sebel Mossman

Measuring reef complexity and rugosity from monocular video bathymetric reconstruction

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Structural complexity of a reef is highly correlated to coral growth rates, coral cover, and overall levels of biodiversity, and is therefore integral in determining ecological processes. Modelling these processes commonly includes measures of rugosity obtained from a wide range of different survey techniques that often fail to capture rugosity at different spatial scales. Here, we show that accurate estimates of rugosity can be obtained from standard video footage captured using underwater video cameras, i.e. monocular video. To demonstrate the accuracy of our method, we compared the results to exact in-situ measurements of a 30x30 m area of Fore Reef from Glovers Reef Atoll, Belize. Sequential pairs of images were used to compute fine scale bathymetric reconstructions of the reef substrate from which precise measurements of rugosity and reef complexity can be derived across multiple

spatial scales. To achieve accurate bathymetric reconstructions from uncalibrated monocular videos, the position of the camera for each image in the video sequence and the intrinsic parameters (such as focal length) must be computed simultaneously. We show that these parameters can be often determined when the data exhibits parallax-type motion, and that rugosity and reef complexity can be accurately computed from existing video sequences taken from any type of underwater camera from any reef habitat or location. This technique provides an infinite array of possibilities for future coral reef research by providing a cost effective and automated method of determining rugosity in both new and historical video surveys of coral reefs.

5D Robots & machine learning techniques aiding coral reef science
Monday 9 July, 1215, Sebel Mossman

Computer vision and data mining methods applied to the recognition of coral specimens

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The coral reefs of the world, like too many other ecosystems, are under constant threats by climate change, invasive fisheries, and coastal pollution. Unfortunately the quantitative evaluation of the damage to this ecosystem and its biodiversity cannot be obtained easily. Marine scientists require automated tools to monitor the status of this fragile coral ecosystem. Here, we aim to provide tools to automate the detection and identification of coral specimens within a vast underwater photographic database. To this end, two approaches have been investigated: identification of corals based on their growth form (benthic forms identification), and accurate identification of species (taxonomic identification). For benthic form identification, various computer vision tools, such as descriptors extracted from the grey-level cooccurence matrix (GLCM), the local binary patterns (LBP), the colour channels histograms, and the Fourier transform, were implemented. These were used in conjunction with machine learning algorithms such as the Bayesian classifier, the nearest neighbours, the C4.5 classification tree, the support vector machine (SVM), and the multilayer perceptron (MLP). Following the study on benthic forms, similar tools were investigated to achieve taxonomic classification. In this portion of the study, the problem of automated segmentation of coral specimens was addressed. A combination of the Laplacian of Gaussian and watershed segmentation techniques was used for automated image tessellation. This was followed by a classification of resulting segments with an optimized SVM. This method proved to be an effective solution to the segmentation problem. Subsequently, coral segments were classified using a different SVM trained for this specific purpose. The results show that it is possible to implement such an automated benthos recognition system. To successfully pursue this investigation, we need a much larger number of classified samples and better-defined feature extraction protocols in order to maximize performance.

5D Robots & machine learning techniques aiding coral reef science
Monday 9 July, 1230, Sebel Mossman

High-definition rotating videos for monitoring reef fish and habitats

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Video techniques are increasingly used for monitoring marine ecosystems. The High-Definition Rotating Videos system (STAVIRO) was developed in 2007 in New Caledonia. It consists of a remote, unbaited and not stereo (uses a single camera) video system equipped with an engine to rotate the camera (rotation through an angle of 60 degrees every 30 seconds) once on site. Since 2008, STAVIROs have been used each year in New Caledonia to survey marine reserves and unprotected areas of the New Caledonian Lagoon; 1467 stations have been validated to date. Field observations are easy, and the amount of information collected confirms that this technique is appropriate for the study of spatiotemporal variations of communities. A comparison of the STAVIRO with a standard Underwater Visual Census (UVC) technique (method of fixed points) was achieved in New Caledonia in 2009 by setting STAVIRO one hour after each UVC. Additional video stations were carried out in the study area over 2 weeks of fieldwork, resulting in 38 stations by each method plus an additional 90 stations for video. Preliminary analyses indicate that overall species richness is greater for UVC, but that i) some taxa are better observed in the absence of a diver, and ii) the large spatial coverage afforded by STAVIRO yields a considerable amount of information that cannot be collected by UVC over a given field work period of time, but the video technique requires additional time to analyze video images.

5D Robots & machine learning techniques aiding coral reef science
Monday 9 July, 1030, Sebel Mossman

Advanced Reef Mapping and Monitoring with Autonomous Underwater Vehicles

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Australia's Integrated Marine Observing System (IMOS) has a strategic focus on the impact of major boundary currents on continental shelf environments, ecosystems, and biodiversity. To improve our understanding of natural, climate change, and human-induced variability in shelf environments, the IMOS Autonomous Underwater Vehicle (AUV) facility has been charged with generating physical and biological observations of benthic variables that cannot be cost-effectively obtained by other means. Starting in 2010, the IMOS AUV facility began collecting precisely navigated benthic imagery using AUVs at selected reference sites on Australia's shelf, focusing primarily on temperate and tropical reefs. This observing program capitalizes on the unique capabilities of AUVs that will allow repeated visits to the reference sites, providing a critical observational link between oceanographic and benthic processes. In 2010 benthic reference sites were established in Western Australia, Tasmania, SE Queensland, and New South Wales (NSW), in collaboration with marine scientists throughout Australia. This presentation covers the relevant capabilities of the AUV facility, the design of the IMOS benthic sampling program, and results from the 2010 and 2011 surveys, with particular focus on the GBR and Scott Reef. We also report on some of the challenges and potential benefits to be realized from a benthic observation system that collects several TB of geo-referenced stereo imagery a year. This includes semi-automated image analysis and classification, visualization and data mining, change detection and characterisation, and coordinating and enabling collaborative analysis for marine scientists across the country.

5D Robots & machine learning techniques aiding coral reef science
Monday 9 July, 1000, Sebel Mossman

Quantifying spatial and temporal dynamics of deep reefs AUV technology

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There is increasing interest in the effects that climate change may have on deeper water reef environments. However, the application of traditional methods (e.g., satellite imagery, aerial photography, diver-based surveys) for mapping and monitoring is predominantly limited to shallow water reefs (less than 30m). Innovations in hydro acoustic multibeam sensors and autonomous underwater vehicles (AUV) means we can now collect high-resolution, targeted imagery in combination with models of reef three-dimensional structure. Here, we demonstrate that these data types can be combined to a) accurately map living coral reef and associated major benthos down to depths of 70m, b) elicit ecological processes that may affect their distribution, and c) precisely repeat habitat surveys over scales from patch to landscape, crossing transitions. Using south Scott Reef Lagoon, Western Australia, as a case study, our approach provides robust spatially explicit models of reef substrate and major biotic groups. The models can be used to plan targeted and ecologically informed monitoring in deep reefs areas were traditional methods would fail.

5D Robots & machine learning techniques aiding coral reef science
Monday 9 July, 1245, Sebel Mossman

Automatic benthic imagery categorisation using hierarchical Bayesian clustering

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Imagery of the benthos collected by multiple Autonomous underwater vehicle (AUV) surveys in a single region can exhibit similar habitats, but in proportions unique to each survey. We present a completely data-driven hierarchical Bayesian mixture model that can discover clusters of like images in such datasets. The purpose of such a model is to quickly summarise and label large datasets of hundreds of thousands of images, with the intention of guiding further scientific research. It is specifically formulated to take advantage of the unique proportions of habitats in each survey to aid inference, and is shown to outperform more conventional clustering models on large datasets of stereo imagery of the benthos collected from multiple AUV surveys. We use a visually derived measure of rugosity as a part of our feature vector for describing the stereo images, and have found it to be very discriminating between habitat types. We have applied this algorithm to datasets gathered off the east coast of Tasmania (100,000 images) and in Scott Reef, Western Australia (more than 250,000 images). The algorithm can easily recognise sand and reef habitats, and can also distinguish between images of, for example, Staghorn coral, Platelet coral, Eklonia etc.

5D Robots & machine learning techniques aiding coral reef science
Monday 9 July, 1130, Sebel Mossman

Texture and color distribution-based classification for live coral detection

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The endangered *Acropora cervicornis* coral has been considered a bellwether for coral reef habitat change. Given the recent discovery of a concentrated region of growth off Belize, our group is studying automatic abundance estimation of live *A. cervicornis* with the goal of future rapid assessment monitoring. While others have had success applying machine learning techniques on color- or texture-based features, our project presents several confounding factors in acquisition and in image content. Since the quadrat images are acquired via homography in post processing, the resulting distortion blurs the characteristic texture of *A. cervicornis* in parts of each image. Coral may also appear at multiple scales across images due to camera distance. To account for these effects, we compute our color and texture features at multiple scales. Additionally, changes in lighting lead to large variation in tone and brightness within and across images. To compensate, we apply bias field correction within images and color normalization across images. Content-based confounding factors include the coral's branching structure and the subtle texture differences between *A. cervicornis* and surrounding algae. We use support vector machines on local color and texture distributions to automatically discriminate between live *A. cervicornis* and all other image content. We present promising results on 63 images for which we have manual segmentations to train with or test against. Our integrative approach and available software may greatly reduce the time cost of future abundance estimates of A. cervicornis, and may be generalized to other coral vision problems.

5D Robots & machine learning techniques aiding coral reef science
Monday 9 July, 1015, Sebel Mossman

Wide field of view full spectrum fluorescence imaging for coral ecology

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In recent years there has been a growing interest in multi-spectral fluorescence imaging on coral reefs. Previous studies have found that fluorescence may be useful as a bleaching indicator and as a means of quantifying cryptic coral recruits. Furthermore, the fluorescence signal can serve as a significant aid in automatic classification of benthic images by adding additional features of classification to images beyond color, texture, and shape. Nevertheless, acquisition of fluorescence images is not fully operational yet for large-scale ecological surveys. Most coral reef fluorescence studies use a spectrometer or macro images that yield very localized readings. Other studies rely on manual surveying. Difficulties in wider area fluorescence imaging arise from the low intensity of fluorescence signals and the need to carefully optimize the optical characteristics of the camera, light source, and filters. Moreover, most consumer cameras have very low sensitivity in the red where chlorophyll fluoresces. In this work, we have developed two complementary imaging systems that make wide field-of-view high-resolution fluorescence imaging possible. One system is a consumer SLR camera modified for increased sensitivity for chlorophyll and wide field of view imaging. The second is a custom fabricated submersible system with four synchronized high quality cameras with optimized narrow band filters. We demonstrate the ability of each system through surveys conducted in the field (Panama) and comparative studies in the lab. Using our systems, key visible-band fluorescent emission bands of ecological interest are captured with a wide field of view and high resolution suitable for automated analysis.

5D Robots & machine learning techniques aiding coral reef science
Monday 9 July, 1115, Sebel Mossman

Theme 6. Physiology & functional biology

6A Cell & molecular biology of symbiosis

Whole organism responses to pre-bleaching thermal stressors

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There are many mechanisms which have been implicated in the breakdown of the coral-algal symbiosis during bleaching events, but the progressive change from a healthy to unhealthy state in the 'whole organism' or holobiont (host, dinoflagellates, and bacterial partners) has not been investigated simultaneously. To better understand holobiont change from a healthy to unhealthy state, the response of the coral host, its dinoflagellate symbiont, and its bacterial partners were investigated in the coral *Acropora aspera* to multiple biotic and abiotic stressors which occur during bleaching events. Significant changes in the holobiont are found not only between the daily minimum and maximum temperatures, but also at temperatures as low as 3°C below the thermal threshold and we find these have significant impacts on coral's capacity to withstand stress events and the cumulative impact of biotic and abiotic stimuli. These results show that the control of thermal stress responses is highly complex in this eukaryote-prokaryote symbiosis and that early changes play key roles tipping the life/death balance during environmental stress prior to the onset of coral bleaching.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1000, MR1

Lipid and fatty acid compositions of *Symbiodinium* sp.

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Many marine invertebrates, including corals, are living in the tropical and subtropical zones and are known to have zooxanthella as symbionts. These invertebrates are considered to cope with environmental stresses by changing membrane lipid and fatty compositions of the symbionts, but details of these contents have not been reported. To evaluate how the invertebrate withstands the stresses, we first examined membrane lipid and fatty acid contents of the symbionts. For these analyses, we chose two strains, KB8 and Y106, of *Symbiodinium* sp. which were isolated from a jellyfish *Cassiopea ornata* and a mantle lobe of a shellfish *Tridacna crocea*, respectively. Dinoflagellate strains were cultured in f/2 medium for 21 days at 25°C. Lipids were extracted from the cells by the Bligh and Dyer method, and separated by two dimensional thin-layer chromatography. Each lipid was then scraped off from the silica plates and fatty acid methyesters were prepared by methanolysis reaction. These methyesters were quantified by gas chromatograph using pentadecanoic acid as a standard. In both strains, three glycolipids (monogalactosyldiacylglycerol, digalactosyldiacylglycerol and sulfoquinovosyldiacylglycerol) are found. These are typical lipids of photosynthetic membranes, indicating that the strains are photosyntheticaly active. As a phospholipid, phosphatidylcholine was the major lipid. This phospholipid is typical for organelles other than the plastids. These dinoflagellates are also found to have long chain unsaturated fatty acids, e.g., octadecatetraenoic acid, octadecapentaenoic acid and docosahexaenoic acid. We will also present the effect of temperature and light intensity to lipid and fatty acid compositions.

6A Cell & molecular biology of symbiosis
P058

Cnidarian TSR proteins and their possible role in cnidarian-dinoflagellate symbiosis

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The thrombospondin type 1 domain or TSR is named after the original human platelet extracellular matrix protein, Thrombospondin 1, that contains three TSR repeats. It has been found that many extracellular matrix and trans-membrane proteins share the TSR domain in various numbers of repeats. This domain is involved in multiple functions from cell adhesion to cell invasion. Although members of the lower Metazoa do not have a classic TSR containing the thrombospondin protein, here we report and describe multiple cnidarian members of the thrombospondin TSR superfamily of proteins. We infer function for cnidarian TSR proteins, by comparison with human TSR proteins of known function and through phylogenetic analysis of domains across a wide range of taxa. These data provide evidence of the early evolution of a large family of TSR proteins. It appears that there is some redundancy of function among extracellular matrix and transmembrane proteins. An interesting comparison with the thrombospondin related anonymous protein family or TRAP family used by the apicomplexan parasites to gain entry into host cells could be important to the study of cnidarians-dinoflagellate symbiosis.

6A Cell & molecular biology of symbiosis
P050

Stress resistance determined by *Symbiodinium* type in a model system

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Several studies have suggested that the *Symbiodinium* type is the major factor in determining the resistance of the cnidarian-dinoflagellate symbiosis to thermal and light stress. However, these studies have been correlational and/or involved experiments performed using coral hosts with heterogeneous genetic backgrounds and life histories, both of which are also likely to affect stress responses. To avoid these complications, we are studying the breakdown of symbiosis in response to stress in a genetically homogenous *Aiptasia pallida* host (clone CC7) with a well controlled life history. We are testing holobionts containing either the native CC7 clade A *Symbiodinium* or distinct *Symbiodinium* types introduced from monoclonal, axenic cultures. To assess responses to various stress conditions, we determined total dinoflagellate numbers using a Guava flow cytometer and normalized to animal size using measurements of total protein. This method is sensitive enough to detect small changes in *Symbiodinium* concentrations, allowing us to define the levels of stress that elicit the first signs of symbiosis breakdown. To evaluate the role, if any, of the host in modulating the stress responses, we compared the holobiont stress responses to those of cultured *Symbiodinium* strains exposed to the same challenges. Initial results indicated that the *Symbiodinium* type has a major impact on the bleaching response of the holobiont. We also used the same strains and stress conditions to determine the relative contributions of different cellular mechanisms (algal expulsion, in-situ degradation of algae, host-cell detachment, and host-cell death) to bleaching under various stress conditions.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1030, MR1

Dimethylsulphide and precursors as antioxidants in the coral-zooxanthellae symbiosis

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Dimethylsulphide (DMS) is the most abundant sulphur aerosol present in the marine atmosphere. DMS may act as a climate regulator of sea surface temperature and incident solar radiation when oxidised to non-sea-salt sulphate, which can produce cloud condensation nuclei that are responsible for the formation of stratocumulus clouds over the ocean. DMS is produced by either enzymatic cleavage of its main precursor, dimethylsulfoniopropionate (DMSP), or reduction of dimethylsulfoxide (DMSO) in various species of marine algae, phytoplankton and coral zooxanthellae. Decreases in DMSP and atmospheric DMS production during natural and induced temperature stress have been hypothesised to occur as a consequence of these sulphur substances being used as antioxidants by hard corals, although no conclusive study has been conducted at this stage. For the first time, a link between the production of these sulphur compounds and antioxidant capacity of the coral-zooxanthellae symbiosis has been investigated in *Acropora* species during basal and stress conditions. Concentrations of intracellular DMS, DMSP and DMSO were correlated with the basal antioxidant capacity against peroxyl radicals, using the ORAC (Oxygen Radical Absorbance Capacity) assay, of freshly extracted coral tissue from *Acropora pulchra, Acropora valida* and *Acropora aspera* collected at Heron Island, southern Great Barrier Reef (GBR). Similar measurements were also conducted under temperature stress exposure on two different clades of zooxanthellae (D1 and C1) extracted and cultured from *Acropora millepora* and *Acropora tenuis* collected at Magnetic Island, central GBR. The significance and implications of these experiments will be discussed.

6A Cell & molecular biology of symbiosis
Tuesday 10 July, 1000, MR1

A lipidomic approach to understanding cnidarian-dinoflagellate symbiosis.

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The cnidarian-dinoflagellate symbiosis is arguably one of the most important partnerships within the marine environment in that it is integral to the formation of coral reefs. However, the regulatory processes that perpetuate this symbiosis remain unresolved. It is essential to understand these processes if we are to elucidate the mechanisms that support growth and resource accumulation by cnidarian host and dinoflagellate symbiont, and conversely the recently observed reduction and/or mortality of corals in response to rapid environmental change. Here, we report on lipidomic studies focused on metabolic activity of the symbiosis and specifically that of lipogenesis of free fatty acids and the potential translocation between the symbionts and host. Free fatty acids were

selected because of their essential multiple roles inclusive of energy production and inter cellular communication. The study applied a new method of enriched stable isotopic (^{13}C) incorporation as a biomarker, combined with HPLC-MS to track utilization of carbon via phototrophic or heterotrophic sources into fatty acid lipogenesis. The results of these studies link with known lipogenesis pathways, but interestingly, do not necessarily align with some common perceptions of a mutualistic symbiosis model.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1015, MR1

Developing aiptasia as a model system: tools for genetic analysis

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The molecular and cellular mechanisms underlying cnidarian-dinoflagellate symbiosis are poorly understood, largely because of the intractability of corals as experimental organisms. The small sea anemone *Aiptasia* offers the chance to develop the tractable model system that is needed. Key to such development will be the establishment of methods for the study of gene function. RNA-mediated gene knockdown (RNAi) has proven effective in many other systems, and Dunn et al. (2007) showed its potential in *Aiptasia*. We are attempting to optimize and standardize RNAi methods for *Aiptasia* by using a diverse array of genes as targets and testing numerous delivery methods for the dsRNA trigger, including chemical transfection, electroporation, feeding, and microinjection. The targets include genes involved in nematocyst formation (nematogalectin), nuclear-envelope structure (lamin), regeneration (wnt3), and development (fibroblast-growth-factor receptor). We are also analyzing the biology of the RNAi response in *Aiptasia*. The recently sequenced transcriptome has revealed key components of the RNAi machinery including Dicer, Argonaute, and an RNA-dependent RNA polymerase, which is of particular interest because it suggests an ability to amplify an initial dsRNA signal by producing many secondary siRNAs. We will investigate this possibility by sequencing small RNAs in after induction of the RNAi response. We are also attempting to develop transgenesis as a genetic tool in *Aiptasia*. Using microinjection of zygotes and electroporation of larvae and adults to deliver transforming DNA (as done successfully in *Hydra* and *Nematostella*), we are attempting to stably integrate tagged copies of the nematogalectin and actin genes.

6A Cell & molecular biology of symbiosis
P051

Antioxidant genes in symbiotic algae from the genus *Symbiodinium*

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The phenomenon of coral bleaching over the last two decades has increased in both severity and regularity, whilst the number of areas affected globally has also increased. Through observational and experimental research the link between increased seawater temperature, high-light, and large scale coral bleaching is now well established. Much work has concentrated on what determines the differences in bleaching tolerance observed in the field during bleaching events. Although many factors have been attributed to determining the temperature tolerance (and therefore bleaching tolerance) of the host-algal association, the role that hosting genetically distinct symbiotic algae may play has gained much focus in the last ten years. However, the cellular processes that eventually lead to coral bleaching are not fully understood. Furthermore, how these cellular processes may affect the temperature tolerance of each algal type is just beginning to be investigated. We present recent work to determine the extent to which thermal tolerance of symbiotic algal types is controlled by differences in their ability to cope with oxidative stress under temperature stress. We characterised several antioxidant genes from *Symbiodinium* and used quantitative PCR to determine the expression level of these genes within different *Symbiodinium* types. Preliminary data suggest that temperature tolerant *Symbiodinium* types tested had the ability to increase the expression of these antioxidant genes following 72 h of temperature stress at 32°C. Future work will concentrate on interpreting this response in greater detail and will determine whether this trend is shared by other temperature tolerant *Symbiodinium* types.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1700, MR1

Revisiting the nature of sexual reproduction in *Symbiodinium*

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Key aspects of the *Symbiodinium* life history are still unresolved, which does not only limit our knowledge

on *Symbiodinium* biology but also our understanding of the symbiosis between these dinoflagellates and cnidarians and our ability to predict the resilience of the symbiotic unit under changing environmental conditions. Whether or not *Symbiodinium* undergoes sexual reproduction is a long-standing question with far reaching implications for the cnidarian-dinoflagellate symbiosis. Observational evidence for gametogenesis in *Symbiodinium* goes back as far as 1962, but these observations were never confirmed. Yet, growing molecular information suggests the occurrence of sexual recombination in these dinoflagellates. We present a novel examination of sexual reproduction in *Symbiodinium*. More than 100 clonal cultures of *Symbiodinium* were isolated from *Aiptasia pallida* and *Sinularia flexibilis*. Selected cultures, mainly of clade B1, were examined by microscopy and flow cytometry throughout all growth phases. Small (1.5-2.5 µm), flagellated cells, fitting the size ratio of vegetative cysts to potential gametes in illustrations by Freudenthal, could be documented in the majority of stationary-phase cultures. These small cells could be separated from vegetative cysts and motile zoospores by filtration and were subjected to the PCR amplification of ITS and 28S rDNA. Sequencing confirmed that the amplicons were of *Symbiodinium* origin. These preliminary results suggest the existence of small *Symbiodinium* cells that fit the previous description of potential gametes. To test whether these cells are indeed gametes, systematic crossing experiments are being carried out and additional phylotypes are also currently being examined.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1530, MR1

Does intracellular pH regulate the cell-cycle in *Symbiodinium*?

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The ecological success of scleractinian corals is dependent on a stable population of its dinoflagellate (*Symbiodinium*) partner. A breakdown in the arrangement may be detrimental to the coral's health, perhaps leading to fatality through starvation if the symbiont population density is reduced. However, the mechanism(s) that regulate the growth of the dinoflagellates in hospite, and hence promote the coordination of host and symbiont cell growth, is unknown. pH is one potential mechanism for regulating symbiont density, as it is known to control progression through the cell cycle in other eukaryotes. Indeed, several studies have shown that, for a eukaryotic cell to enter mitotic division, an increase in alkalinity is required. We used the ratiometric fluorescent SNARF-4F probe in conjunction with confocal microscopy to measure the intracellular pH (pH_i) in both the coral host cell and the dinoflagellate symbiont, in the sea anemone *Aiptasia* sp. under a range of ambient pH levels. We then tested whether pH, in particular of the perialgal space and dinoflagellate cell itself, influences cell-cycle progression. To do this, external pH of *Symbiodinium* cultures was lowered via the injection of gaseous CO_2, whilst the dinoflagellate cell cycle was monitored via flow cytometric analysis of cellular DNA content. Our data will be discussed in terms of the potential role of pH in regulating the cell cycle of symbiotic dinoflagellates, and the influence that ocean acidification might have on the intracellular pH of these photosynthetic symbionts and their proliferation in cnidarian hosts.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1745, MR1

Determining light harvesting complex expression in *Symbiodinium* during thermal stress.

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Mutualistic endosymbioses observed between photosynthetic dinoflagellates of the genus *Symbiodinium* and reef-building corals are crucial to the success of diverse reef ecosystems. Studies have indicated that short term heat stress (24 h) in a thermally sensitive *Symbiodinium* A species resulted in photobleaching due to decreases in the gene expression and protein abundance of light-harvesting protein complexes (LHCs). In photoautotrophs, LHCs bind chlorophylls (Chl) and carotenoids for the capture and transfer of solar energy to photosystem reaction centres for photosynthesis. *Symbiodinium* integral LHCs, Chl a-Chl c_2-peridinin protein complexes (acpPCs) are encoded by an extremely diverse family of acpPC binding genes. This study aimed to examine the effect of a 7 day stress at three different temperatures (28℃, 31℃ and 34℃) versus control conditions (25℃) on acpPC gene expression and acpPC protein expression in the thermally tolerant *Symbiodinium* C1 species and to link changes in acpPC expression to alterations in photosynthetic activity. At higher temperatures (31℃ and 34℃) measures of photosynthetic integrity (dark adapted yield and non-photochemical quenching) decreased at days 5 and 3, respectively. Decreases observed in the relative expression of acpPC protein in cells incubated at temperatures exceeding 31℃ correlate with changes observed in photosynthetic activity. The expression of three acpPC genes was determined by quantitative PCR and a significant up-regulation was found in cells incubated above 31℃ throughout the thermal stress. These results indicate that though the mechanism is not known, the regulation of the acpPC protein is at the translational or post-translational stage.

6A Cell & molecular biology of symbiosis
P052

Nitric oxide production in *Symbiodinium* cells varies among different genotypes.

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Nitric oxide (NO) is a reactive and highly diffusive gas that is employed as a messenger molecule by a multitude of organisms. Its use in animals' immune responses to pathogens is well known but recent evidence suggests an important role in the mediation of intracellular symbioses. For instance, in the symbiosis between cnidarians and photosynthetic dinoflagellates of the genus *Symbiodinium*, temperature-induced breakdown of the association appears to be regulated by host-derived NO, and it is hypothesized that this may represent a host innate immune response. However, we confirm here that *Symbiodinium* cells themselves also produce NO as a function of temperature and that this may be linked to their subsequent apoptosis-like mortality. Moreover, responses to elevated temperature were found to differ significantly between genotypes (ITS2 clades A1, B1, C1, D, E2 were examined). For example, cells of a sensitive *Symbiodinium* type (B1) performed extremely poorly at 32°C and 34°C, with photosynthetic yields declining precipitously from control levels and significant increases in cell mortality. This correlated with a sustained increase in NO production over the experimental period relative to cells maintained at control temperatures. In a more tolerant *Symbiodinium* type (C1), however, the opposite was observed: no production declined relative to controls and levels of cell mortality (both apoptotic and necrotic) were depressed at the higher temperatures. These findings highlight the diversity of stress responses among different symbiont types, even in the case of highly conserved phenomena such as nitric oxide signalling.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1645, MR1

Genetic regulation of zooxanthella uptake and regulation in sponges.

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Zooxanthellae symbioses are arguably the most important ecological interaction on coral reefs because they energetically subsidize the entire community, and enhance the calcification process that provides structure for all other organisms. We will present some of our recent work examining the genetic regulation, physiological integration, and ecological/evolutionary significance of *Symbiodinium* harbored by sponges. We argue that this system offers important insights into the associations found in scleractinian corals and all other *Symbiodinium*-based symbioses. Using suppressive subtractive hybridization and transcriptomic-based approaches, we will present new data that identifies genes that appear to be differentially regulated upon uptake of *Symbiodinium* by *Cliona varians*. We have also followed the course of *Symbiodinium* infection in *Cliona varians* forma varians through time, and correlate this process with the genetic regulatory pathways identified above. We will present data on the physiological integration that comes from a series of experiments employing stable isotopic labeling of photosynthetically-derived and heterotrophically-derived material. We also will report findings from a series of heating experiments that show that the photoacclimatory capabilities of the type of zooxanthellae found in *C. varians* may help explain why many sponges appear less sensitive (i.e., they show limited/no signs of bleaching) to thermal stress than corals. Finally, we will discuss two new hypotheses (the magnesium inhibition (MIH) and arrested phagosome (APH) hypotheses) in the context of all host-*Symbiodinium* associations.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1515, MR1

Characterization of VLK protease from *Symbiodinium* sp. strain KB8

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A protease with a t-butyloxycarbonyl-Val-Leu-Lys-4-methylcoumaryl-7-amide (Boc-VLK-MCA) hydrolyzing activity was purified from *Symbiodinium* sp. strain KB8. This strain was previously isolated from the jellyfish *Cassiopea ornata* and cultivated in f/2 medium for 21 days at 25°C. After precipitating the crude extracts with 35% saturation of ammonium sulfate, the enzyme was highly purified by three steps of successive chromatography using DEAE-Toyopearl 650M, DE52 and HiLoad 16/60 Superdex 200 gel filtration. The enzyme was purified about 100-fold estimated by hydrolyzing activity of the substrate. Among six fluorogenic peptides tested, this protease was found to cleave Z-LLE-MCA, with activity about half of Boc-VLK-MCA. Other substrates were less than 25%. This enzyme activity was almost completely inhibited by cysteine and serine protease inhibitors such as leupetin and E-64, whereas EDTA inhibited 33% at a concentration of 1 mM. Pepstatin had also slightly inhibitory effects (37% inhibition at 0.01 mM). These results suggest that this enzyme is not metallo or aspartic protease. More data are required to determine whether this enzyme is cysteine or serine protease. pH optimum of the enzyme was estimated to be pH 4 by the analysis in the ranges from pH 3 to 9. From the triplicate data at six concentrations of

the substrate from 0 to 200 µM, the Km and Vmax values were calculated to be 140 µM and 79 µM/min for Boc-VLK-MCA, respectively. We are now cloning the cDNA of this enzyme.

6A Cell & molecular biology of symbiosis
P053

Use of *Symbiodinium* to study the lipid regulation during the cnidaria-dinoflagellate endosymbiosis

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Lipid body (LB) formation in both the host cell and symbionts is one of the pivotal phenomena during the marine cnidaria-*Symbiodinium* endosymbiosis. The aim of this study is to investigate lipid compositional changes by artificially inducing LB accumulation in *Symbiodinium* sp. (clade B) under a nitrogen-limitation culture. Free-living *Symbiodinium* originally isolated from the sea anemone *Aiptasia pulchella*, were cultivated in either the normal or nitrogen-limitation medium under a normal 12h:12h light:dark photoperiod. Significant lipid accumulation was observed in the treated *Symbiodinium* based on lipid and imaging analyses. The imaging analysis using fluorescent probes (Nile Red and BODIPY 493/503) indicated that there was increasing lipid bodies accumulation in *Symbiodinium* during the nitrogen-limitation treatment. This was concurrent with the concentration elevations of intracellular triacylglycerol and wax ester. The accumulation of lipid bodies was also confirmed by transmission electron microscopic examination, which demonstrated a peculiar LB structure with electron-transparent inclusions. Our results indicate that LB formation in the *Symbiodinium* can be induced by limiting the nitrogen resource; a regulation mechanism which possibly operates during the endosymbiotic association.

6A Cell & molecular biology of symbiosis
P054

Impacts of thermal stress on sphingolipid metabolism in *Aiptasia pallida*

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Breakdown of the mutualistic symbiosis between dinoflagellates, *Symbiodinium* sp., and cnidarians hosts can be brought on by numerous environmental stressors, most notably by elevated temperatures. Thermal stress can initiate host immune responses leading to a destabilization of the symbiosis and result in the loss of symbionts from the host tissue. Sphingolipid metabolites, sphingosine and sphingosine-1-phosphate (S1P), are suspected to be part of the host immune response. Sphingolipids act as important signaling molecules in the regulation of stress response, cell proliferation, and apoptosis. The balance of the sphingosine and S1P is regulated by the expression of the so called 'sphingosine rheostat'. Sphingosine kinase phosphorylates sphingosine into S1P and conversely S1P is dephosphorylated to sphingosine by sphingosine-1-phosphate phosphatase. Elevated levels of S1P promote host cell survival and partially rescue heat-stressed *Aiptasia pallida* from bleaching. Therefore, modulation of the balance of sphingolipids could play a significant role in host-symbiont interactions. The expressions of sphingosine kinase and sphingosine-1-phosphate phosphatase were examined under elevated temperatures with different durations of stress in *A. pallida* using qRT-PCR. In addition, liquid chromatography tandem mass spectrometry analysis of lipid extracts under the same thermal stress conditions was performed to quantify the S1P levels. Collectively, this data indicates that sphingolipid signaling could play a regulatory role in the breakdown of dinoflagellate-cnidarian symbiosis.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1230, MR1

NanoSIMS study of ammonium assimilation by the coral *Pocillopora damicornis*

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In the present work, the metabolism of nitrogen within the coral-zooxanthellae symbiotic association is investigated at a cellular level in the reef-building coral *Pocillopora damicornis*. By combining TEM ultrastructural observations and quantitative NanoSIMS isotopic imaging of tissue sections at high spatial resolution (~70 nm), the assimilation of 15N-ammonium and the fate of the 15N-organic compounds within each symbiotic partner can be studied directly. From a 1-hour initial pulse of 20 µM $^{15}NH_4Cl$ and a 95-hours chase study we make the following key observations: 1) Zooxanthellae are confirmed to be the primary site of ammonium assimilation and display a high sub-cellular heterogeneity in their ^{15}N-enrichment. 2) Possible nitrogen-storage structures, rapidly formed and subsequently mobilized, are identified within the algal cells. 3) Assimilation of ammonium by the host occurs at a significantly lower rate, but takes place in all four cellular layers composing the coral tissue. 4) Ammonium assimilation by the zooxanthellae is confirmed to be substantially lower at night after a prolonged pre-incubation in darkness, taking place at similar rate as in the host cells (day or night). 5) The experiment shows little evidence for nitrogen

translocation from the zooxanthellae to their coral host tissue. Our observations suggest that ^{15}N-organic compounds within the coral host tissue are engaged in anabolic pathways, e.g. the synthesis of mucus. We discuss our results in the context of the long-standing debate between the 'Nitrogen-recycling' versus 'Nitrogen-conservation' hypotheses in cnidarian-zooxanthellae symbiosis.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1200, MR1

Symbiodinium under thermal stress: type specificity in the antioxidative response

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The Oxidative Theory of Coral Bleaching identifies the excessive generation of reactive oxygen species (ROS) in coral symbionts and their leakage to the host as a major cause of the breakdown of the symbiosis. However, bleaching thresholds depend on host-symbiont pairings and vary between *Symbiodinium* types. Here we attempted to elucidate the physiological basis by comparing the response of various *Symbiodinium* types (B1, C1, E2, F5) to a thermal gradient under low light over two weeks of exposure. This study focused on ROS-scavenging pathways, as well as their link to the glutathione system and its capacity to remove products of oxidative damage. Thermal sensitivity, determined as growth and photosynthetic efficiency (Fv/Fm), differed between these *Symbiodinium* types in the order F5>E2>B1; data for C1 are currently being analysed. Of particular note, *Symbiodinium* F5 exhibited no decline in Fv/Fm at 33°C over the course of the experiment. While the activities of enzymes such as superoxide dismutase, glutathione reductase and glutathione S-transferase differed significantly between strains, a common stress response such as an increase in total glutathione content or an up-regulation of ascorbate peroxidase activity was observed. The extent of these general stress reactions varied, however, with time and symbiont type. Based on the activity of the monitored pathways, the presence of particular ROS and their potential cellular impacts were compared between symbiont types and stress levels. Whether selective augmentation of elements of the antioxidant network can explain differing thermal thresholds in the four *Symbiodinium* types studied will be discussed.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1130, MR1

Photosynthesis induced changes in intracellular pH in the coral-algal symbiosis

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The regulation of intracellular pH is part of cellular homeostasis in all organisms. In symbiotic cnidarians such as reef corals, it also influences the transfer of ions (e.g. dissolved inorganic carbon) from the surrounding seawater to *Symbiodinium* cells in the host endoderm tissue. Recent research has shown that photosynthetic activity of dinoflagellate symbionts may cause significant shifts in the pH_i of corals. Shifts in pHi have the potential to profoundly affect coral cell metabolism, but to date little is known about the dynamics of the process or the underlying mechanisms. Using confocal microscopy and the pH sensitive probe SNARF-1 AM, we investigated pH regulation in symbiont containing and symbiont free *Stylophora pistillata* cells exposed to a range of light levels for different durations. Live cell imaging was performed under perfused seawater allowing for the control of external parameters (pH, oxygen and temperature) and the introduction of inhibitors for mechanistic studies. Our results reveal the extent and rate of change in host cell pH_i and provide insight into the mechanisms underpinning pH regulation in corals. These findings are an important step towards a better understanding of the physiological interactions occurring between corals and their dinoflagellate partners. Our work on coral pH regulation also compliments the growing field of research that investigates the impact of declining ocean pH on coral symbiosis and calcification.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1500, MR1

The characters of lipid body dynamic formation during the early coral development

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The gastrodermal lipid bodies (LBs) have been identified as a complex and dynamic organelle and are characteristic for the endosymbiosis with *Symbiodinium* in stony corals. The present research investigates the endosymbiotic activity of the coral-dinoflagellate interaction during the early development of corals. Due to their symbiosis-dependency in lipid composition and ultra-structure, LBs were used as a bioindicator for the endosymbiotic activity in planula larvae of the hermatypic coral Seriatopora hystrix. *In situ* distribution of larval lipids was examined by osmium tetroxide labeling. During the larval development, populations of LBs appeared in both the epidermis and gastrodermis. Unexpectedly, LBs could not be clearly identified in the larval gastroderm due to the presence of numerous osmium tetroxide-labeled yolk bodies. On the contrary, the dynamic LBs

distribution in the epiderm is significant. Upon the settlement of the planula, LBs increased to form bilayers within 48 hours. The LBs gradually redistributed to form one layer three to four weeks after the settlement. Using high performance thin layer chromatography (HPTLC) the composition of lipids in larvae was analyzed. It showed, during the settlement process, the total wax esters gradually decreased and with a concurrent increase of triglycerides. The study demonstrated that the initial endosymbiotic activity in floating plaunlae is low, while the following settlement and metamorphosis resulted in the increased of the endosymbiotic activity. The changes of lipid composition in larvae may reflect the regulation of endosymbiotic activity during the coral development.

6A Cell & molecular biology of symbiosis
P055

Rhodopsin-based visual system in coral larvae

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We report an unexpected discovery that coral larvae can distinguish color. Our experiments with larvae of two Caribbean corals, *Porites astreoides* and *Acropora palmata*, demonstrated that they settle and metamorphose at a greater frequency on red substrata than similar surfaces of other colors. Preferential attachment to red objects was not observed in darkness, showing that this behavior was guided by a visual cue. Using BLAST and PCR, we cloned three full-length cDNAs encoding seven-pass transmembrane receptors from *A. palmata* larvae. These proteins (Acropsins 1-3) resemble both vertebrate and invertebrate opsins, e.g. contain characteristic lysine residue known to couple to retinal. We developed antibodies against Acropsin 1 and Acropsin 2, which detected 37kDa and 40kDa bands corresponding to the predicted molecular weights on coral immunoblots. Immunofluorescence microscopy showed that Acropsin 1 is localized in the larval gastroderm, whereas Acropsin 2 is localized in a small population of epithelial cells, with higher abundance in the aboral end. We also cloned orthologs of vertebrate Gi, Go and Gq (72-84% identity) and a novel G protein that has 39% identity to Gi and some unique features. We expressed acropsins in mammalian cells, reconstituted with 11-cis-retinal and showed that they can activate some of the coral G proteins in a light-dependent manner.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1215, MR1

Characterization of peridinin-chlorophyll protein complex of *Symbiodinium* sp. Y106

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Pigment composition and pigment protein complex of *Symbiodinium* sp. strain Y106 were analyzed by high-performance liquid chromatography (HPLC) and sucrose-density gradient centrifugation. The stain was isolated from a mantle lobe of *Tridacna crocea* and cultivated in f/2 medium for 21 days at 25℃. HPLC analysis was performed using a Waters Symmetry C8 column and a programmed binary gradient elution with a photodiode array detector. The pigments were quantitatively analyzed and identified by comparison with the standards. HPLC analysis separated 9 species of the pigments and all of them were annotated. A marker pigment of dinoflagellate, peridinin, was the most abundant carotenoid. Next, we examined the pigment-protein complex from the membranes of this alga after solubilized with ß-dodecyl maltoside using a sucrose density gradient centrifugation of 5-20% at 200,000 x g for 16 h. After the centrifugation, five color bands were obtained. The center band was orange red and most probably contained peridinin-chlorophyll protein complexes (PCPs). Each Fraction was characterized with respect to its pigment composition, spectroscopic characteristics, and polypeptide composition. The center band showed strong absorbance between 450 and 565 nm due to the carotenoids bound to the PCPs, mainly peridinin. Chl *a* in the complexes appeared at 672 nm, while Chl *c* peak was only visible as a small peak at 636 nm. We are now analyzing the polypeptide by a gel electrophoresis coupled with mass spectrometry, and will present the results.

6A Cell & molecular biology of symbiosis
P056

Temperature induced differences in oxygen consumption and growth rates of 6 *Symbiodinium* types

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Although dinoflagellate symbionts are critical to coral reef maintenance, growth, and persistence, little is known about their physiology, especially how it relates to genetic diversity that exists within the *Symbiodinium* genus. In particular, gaps surround our understanding of variation among different symbionts, and how that physiology changes during exposure to stressors associated with climate change, such as elevated temperatures. To

investigate this, 6 different *Symbiodinium* cultures (types A1, A2, B1, B2, E1 and F2) were exposed to a range of temperatures and the resulting oxygen consumption rates, growth rates, and production of apoptosis markers were measured and compared. Cultures were acutely exposed to temperatures ranging from 25℃ to 37℃ (42℃ for F2) and dark oxygen consumption rates were measured, allowing determination of maximum oxygen consumption rates and Q10 rates. Differences existed among algal types for the maximum rate, temperature where maximum rates were reached, which ranged from 31℃ (B1) to 41℃ (F2), and Q10 rates, with the lowest at 2.804 (E1) and the highest at 5.880 (B2). Growth rates at 25℃, 30℃, 32℃ and 34℃ were also measured and differences among *Symbiodinium* types were again observed. Preliminary analysis suggests that in some *Symbiodinium* types, oxygen consumption continued beyond temperatures where positive growth rates were maintained, indicating that algal cells are still alive at these temperatures but unlikely able to support their own growth. These findings will be applied to elucidate the physiological responses of *Symbiodinium* to stressors associated with climate change and address their role in coral decline.

6A Cell & molecular biology of symbiosis
Tuesday 10 July, 1015, MR1

FISH-Flow: a quantitative molecular approach for describing populations of *Symbiodinium*

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Our understanding of coral reefs and their fate in a changing climate is limited by our ability to monitor the diversity and abundance of the algal endosymbionts that sustain them. This study combined two well-known methods in tandem: Fluorescent *In situ* Hybridization to genetically distinguish and label zooxanthellae, and Flow Cytometry to quantify the abundance of each strain in a sample. This technique (FISH-Flow) was developed with cultured *Symbiodinium* representing four distinct phylotypes (based on 28S rDNA), and was used to distinguish and quantify these types with high efficiency and few false positives. This technique was also applied to freshly isolated symbionts of experimentally bleached and healthy *Montastrea annularis*. Host isolates from bleaching tissues had significantly lower labeling efficiency; however, host isolates from healthy tissue had efficiencies comparable to cultured *Symbiodinium* trials. Coral mucus or RNA degradation in bleaching samples may have interfered with labeling of cells. Nevertheless, we were able to determine that in response to thermal stress, experimental columns of the coral *Montastrea annularis* hosted a majority of clade B and B/C symbionts on the top and side of the coral column, respectively. The method developed here may have broader uses in investigation of coral-symbiont interactions and in monitoring reef health.

6A Cell & molecular biology of symbiosis
P057

Lipid and fatty acid compositions of coral and dinoflagellate

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Most corals are a symbiotic system because they harbor zooxanthellae. This system is exposed to external and internal environmental stresses; the former includes factors such as increased seawater temperature, strong sunlight, while internal stresses by reactive oxygen species (ROS) would be unavoidable in normal symbiosis. The incomplete reduction of molecular oxygen in the respiratory chains produces hydrogen peroxide and super oxide radical anions even under normal conditions. The ROS produced in corals are likely to become an oxidative stress to symbionts. While the light reaction in symbiont photosynthesis produces singlet oxygen molecules under excess light conditions, which should affect the physiological activities of their coral host. Host corals and zooxanthellae are known to contain high levels of long-chain polyunsaturated fatty acids, such as docosahexaenoic acid (DHA), as a component of polar and neutral lipids, as well as other marine organisms. The artificial liposomes of phospholipid comprising DHA and hexadecanoic acid (16:0) generate a bilayer structure, and 'the hydrophobic' third layer consisting of the alkyl chain of 16:0 can be formed between the two layers. The presence of this hydrophobic layer is known to constrain a passing of ROS through the cell membrane in bacterial systems (the membrane-shielding effect). In this paper, we analyzed lipid and fatty acid compositions of host corals and zooxanthellae separately, with a special emphasis of the distribution of DHA, and discuss the involvement of the membrane-shielding effect in the maintenance of the symbiosis of corals.

6A Cell & molecular biology of symbiosis
Tuesday 10 July, 1030, MR1

The role of complement in cnidarian-dinoflagellate symbiosis

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Cnidarians, such as corals and sea anemones, are important organisms to study because of their ecological and evolutionary significance. Many corals and anemones engage in symbiotic relationships with photosynthetic dinoflagellates of the genus *Symbiodinium*, which form the basis for the high productivity and diversity of coral reef ecosystems. Cnidarians are basal metazoans and understanding the molecular mechanisms by which these organisms recognize, acquire, and maintain symbionts within their cells is informative in the context of host-microbe interactions and understanding ancestral immune pathways. The research presented here will focus on the complement system, an innate immune pathway that in vertebrates promotes phagocytosis and destruction of invading microbes. Recent studies have suggested a role for complement in invertebrate immunity, and specifically in cnidarian-dinoflagellate symbiosis. I have characterized complement proteins factor B and MASP in the anemone *Aiptasia pallida* and performed functional studies to better understand the role of these molecules during the onset of symbiosis. Data presented will include qPCR results for the expression of factor B and MASP during the onset of symbiosis as well as results from in-situ hybridizations. Overall, this research will lead to a greater understanding of the function of the ancestral complement pathway and its role in cnidarian-dinoflagellate symbiosis.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1545, MR1

Symbiodinium clade dynamic in corals facing environmental stressors in Moorea

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Corals are seriously threatened by global and local changes, mainly due to the fragility of their vital symbiosis with *Symbiodinium*. Clades of *Symbiodinium* are extremely diverse and characterized by different eco-physiological capacities, which may play a key role in coral health. While there are numerous studies on the importance of zooxanthella diversity in corals in response to stress, long -term comparative surveys of zooxanthella diversity in corals facing various environments are extremely scarce. To fill this gap, a 12 month temporal survey of *Symbiodinium* community has been investigated on tagged coral colonies of *Acropora* spp. and *Pocillopora damicornis* in four different sites around Moorea Island. These sites are characterized by contrasted conditions (e.g., sedimentation, nutrients, chl a, pollution). The proportion and diversity of 6 clades of zooxanthellae (A-F) were investigated with the real-time quantitative polymerase chain reaction technique. Our preliminary results indicate a difference of *Symbiodinium* community between both genus *Acropora* and *Pocillopora*. Moreover, a higher proportion of clade D in *P. damicornis* was observed in the most impacted site. This suggests that changes in the proportion of zooxanthella clades are linked to the environmental conditions. This project will provide new insights on the temporal dynamic of zooxanthella clades in corals in response to stress and a deeper understanding of coral tolerance. Further works are exploring the role of other endosymbiotics partners (e.g. bacteria) in corals, which may also play an important ecologic role in coral resistance.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1715, MR1

Effects of temperature on integrin distribution in the aposymbiotic anemone *Aiptasia pulchella*

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Temperature-induced cnidarian bleaching can result from several different cellular phenomena, including loss of cell adhesion and apoptosis. We have been investigating the role of the cell-substrate adhesion molecules, integrins, in temperature-induced coral bleaching. Integrins mediate a variety of signaling pathways that control cell survival and proliferation as well as cell adhesion. Using two different antibodies, we have previously shown that there are large amounts of integrins localized at the base of the ectoderm and endoderm in the symbiotic sea anemone *Aiptasia pulchella*. Temperature shock from 25°C to 30°C for more than 12 h reduces this integrin staining compared to control animals. We are currently investigating whether temperature shock from 25°C to 30°C affects integrin distribution in aposymbiotic anemones to determine the role of the algae in this phenomenon. The distribution of integrins in aposymbiotic anemones that have been temperature shocked for 12 and 24 h is similar to control animals. These data suggest that temperature shock affects symbiotic and aposymbiotic anemones differently and suggests temperature stress to the symbiotic algae contributes to the altered distribution of integrins observed in symbiotic anemones. We are currently investigating additional time points to clarify how temperature affects integrin distribution. In addition, we are investigating how downstream signaling from the integrins is affected by temperature stress.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1145, MR1

Caspase-controlled coral bleaching: is it common?

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Caspase proteins play a central role in pathways leading to apoptosis (i.e., the removal of damaged cells) in all multicellular animals, including basal metazoans. Moreover, apoptosis is one of several mechanisms by which cnidarians are known to lose algal symbionts in response to stress stimuli. Caspase activation under heat stress in a cnidarian was first reported in the sea anemone, *Anemonia viridis*, undergoing bleaching. Recently, Tchernov et al. (2011) suggested that the caspase-dependent apoptosis pathways underpin the bleaching response in corals and proposed a model for coral resistance to thermal bleaching that involves the down-regulation of caspase-mediated apoptosis. However, chemical inhibition of caspase activity has failed to prevent heat-stress bleaching in the anemone, *Aiptasia pallida*. In order to evaluate how common caspase-mediated bleaching is in the coral thermal stress response, here we test the prevalence of this phenomenon across multiple species. We conducted thermal bleaching experiments on five coral species collected from Ofu Island, American Samoa, including four *Acropora* species and *Pocillopora damicornis*. Our results show that one-hour incubations in the caspase inhibitor used by Tchernov et al. failed to prevent thermal bleaching in the four *Acropora* species and in *P. damicornis*. These results suggest that corals in this experiment bleached via mechanism(s) other than caspase-mediated apoptosis, and/or that the caspase inhibition treatment was insufficient to completely prevent the apoptosis pathway. Although follow up experiments are needed, these initial findings suggest caution in assuming that apoptosis is the primary mechanism of bleaching in most corals.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1115, MR1

Role of GFP-like proteins during key stages of the symbiosis

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It has long since been proposed that the host helps regulate the internal light field for the benefit of the algal symbionts via mechanisms such as multiple scattering and the production of photoprotective/photoenhancing pigments. In particular, GFP-like proteins have been proposed to alter the intensity and composition of the light field experienced by the symbionts. Nevertheless, their function in host-symbiont interactions remains controversial due to a lack of mechanistic evidence, especially at the cellular and molecular levels. To improve our understanding of the role of these proteins at key stages of the coral-symbiont relationship, we investigated the regulation of a suite of GFP-like proteins in the establishment, stasis, and breakdown of the symbiosis using a suite of molecular biological and spectroscopic techniques. Firstly, we will discuss the role of GFP-like proteins in photoprotection, their regulation and their link with new tissue growth and establishment of symbionts. Secondly, we will focus on how the host maintains the symbiosis using species-specific mechanisms in controlling the levels of these proteins present in the host tissue. A combination of semi-quantitative reverse transcriptase polymerase chain reaction, immuno-histochemical and spectroscopic analyses show that both transcriptional and post-translational regulation mechanisms are used by species from different light environments. Lastly, we will explore the effects of light and temperature stress on the expression of these proteins and the implications for coral bleaching. These data provide an insight into the different regulatory mechanisms used by the coral host in successfully maintaining the coral-dinoflagellate symbiosis.

6A Cell & molecular biology of symbiosis
Tuesday 10 July, 0930, MR1

Normal *Symbiodinium* lipid synthese are prerequisite for the symbiont-anemone recognition

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Sea anemone *Aiptasia pulchella* naturally hosts a culturable clade B *Symbiodinium* in Taiwan and is therefore an ideal animal model for endosymbiosis studies. Lipids are a source of metabolic energy and essential components of cellular membranes, and furthermore, play important roles in the cell proliferation and cell cycle progression. The effect of lipid synthesis in regulating the cell cycle progression in free-living *Symbiodinium* (clade B) was modulated by cerulenin, a fatty acid synthesis inhibitor. With cerulenin treatment, syntheses of fatty acids and phosphatidyethanolamine (PE), but not phosphatidylcholine (PC), were significantly inhibited. The cerulenin-treated *Symbiodinium* failed to establish a successful endosymbiotic association with *A. pulchella*, with only a 16.5% of the treated *Symbiodinium* infected rate. Furthermore, cerulenin significantly inhibited the cell proliferation of *Symbiodinium* by arresting cell cycles at their G0/G1. As a consequence, once cerulenin infected

the gastroderm of *A. pulchella*, the total number of treated *Symbiodinium* per *A. puchella* barely increased, and resulted in a density 9.74 fold lower than its control counterpart. This indicates that fatty acids and/or PE in *Symbiodinium* may play a critical role during the initial recognition step and their subsequent proliferation inside the host cells.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1630, MR1

Coral recruits obtain energy from algae prior to *Symbiodinium* acquisition

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Most broadcast spawning coral larvae do not contain *Symbiodinium*. Symbionts are usually acquired post-settlement from the environment when available, commonly ~10 days after settlement. Mortality rates are high in newly settled corals, and the reasons for this are poorly understood. A population of recruit acroporid corals was raised and, 7 weeks after settlement, many of these recruits had survived without acquiring *Symbiodinium*. All of the recruits without *Symbiodinium* had settled on crustose coralline algae (CCA) or had endolithic green algae within their skeletons. Growth of these asymbiotic recruits was not significantly different than that of corals that had acquired *Symbiodinium*, suggesting that the asymbiotic recruits may have acquired photosynthates from the CCA or the endolithic algae. To test this hypothesis, we used ^{14}C to trace translocation and uptake between algae and asymbiotic corals. Recruits were incubated in ^{14}C enriched seawater for a 10 hr photoperiod. Following incubation, recruits were separated from the algal substrata and ^{14}C activity quantified using a Trilux scintillation counter. Our results indicate that ^{14}C was present in the asymbiotic coral tissue, suggesting that carbon had been translocated from the underlying algal substrata to the coral tissue. We suggest that CCA and endolithic algae provide a primary energy source that allows recruits to survive and grow until acquisition of *Symbiodinium*. Numerous studies have shown that coral larvae preferentially settle on CCA due to chemical and bacterial cues, and our results provide a compelling mechanism for this substrate preference by coral recruits.

6A Cell & molecular biology of symbiosis
Monday 9 July, 1730, MR1

Sulfur utilization by coral-algae endosymbiosis

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Reef-building corals are in mutualistic symbiosis with the dinoflagellates of the genus *Symbiodinium* for growth and skeletal formation. However, little is known about the relationship between algal endosymbiosis and coral skeletogenesis. In our previous study, the expression of sulfate transporter mRNA was up-regulated by the presence of *Symbiodinium* cells in juveniles of the reef-building coral *Acropora tenuis*. Therefore, sulfate utilization may be important to coral-algae endosymbiosis. In this study, we performed autoradiography using ^{35}S-labeled sufate ions to examine the transport pathway of the SO_4^{2-}ions in the coral. We confirmed the ^{35}S distribution in coral tissues by light microscopy. The incorporated ^{35}S was mostly detected around the symbiotic algal cells and inside the symbiotic cell. These results suggest that ^{35}S was transported into the symbiotic cells and used to synthesize sulfated compounds. It is known that sulfur assimilation occurs in plastid of plant and the product, sulfur amino acid, is essential for most organisms including animals. Therefore, we speculate that the SO_4^{2-}ions taken up by corals are transported to symbotic algae, and the algae synthesize sulfur amino acids, which is then transported to the coral tissues. Transported 35S was also detected in ectodermal cells including many mucus cells and endodermal cells near the skeleton. Mucus and skeleton of the coral are composed in part of polysaccharides, so that it may be that SO_4^{2-} was incorporated into the polysaccharide to form sulfated compounds.

6A Cell & molecular biology of symbiosis
P060

Symbiont flexibility in *Galaxea fascicularis* across the South China Sea

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Reef corals form obligate endosymbioses with dinoflagellates (zooxanthellae) belonging to the genus *Symbiodinium*, and the ecologically distinct *Symbiodinium* is thought to influence to the resilience of reef ecosystems to climate change. Using a combination of the internal transcribed spacer region 2 (ITS2) and denaturing gradient gel electrophoresis (DGGE) analyses, we assessed the variability of *Symbiodinium* in the widely distributed species *Galaxea fascicularis* along latitudinal transect from tropical to subtropical regions in the South China Sea. Three unique *Symbiodinium* ITS2 types belonged to clade C and D were observed in all colonies. The stress-tolerant *Symbiodinium* ITS2 type D1a showed a latitudinal distribution from north to south, most likely a result of a gradient in sea surface temperature (SST) driven by long-term ecological and evolutionary processes. Furthermore, we highlight that such tremendous spatial flexibility may act as a potential adaptive mechanism for the holobiont during environmental change.

6A Cell & molecular biology of symbiosis
Tuesday 10 July, 0945, MR1

6B Mechanisms of calcification

The composition of coral calcification fluid: insights from skeletal chemistry

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We analysed the skeletal chemistry of a suite of *Pocillopora damicornis* colonies, cultured in the presence of the Ca-ATPase inhibitor, ruthenium red. Suppression of Ca-ATPase decreased significantly skeletal $\delta^{11}B$ (reflecting calcification fluid (ECF) pH), increased Ba/Ca and B/Ca, but did not affect Sr/Ca. The ECF pH decrease in the Ca-ATPase inhibited corals compared to the control corals is ~0.25 units. Assuming that Ca-ATPase exchanges $2H^+$ for each Ca^{2+} transported into the calcification site, we calculate that ~11% more of skeletal Ca^{2+} is pumped via Ca-ATPase in the control corals, compared to the inhibited corals. Assuming that Ba^{2+} does not substitute for Ca^{2+} during Ca-ATPase transport and that Ca-ATPase activity effectively dilutes the Ba/Ca of the ECF, then this figure is in agreement (within error) of the observed increase in skeletal Ba/Ca between the control and inhibited corals (~18%). Skeletal B is derived from borate [$B(OH)^{4-}$] which probably substitutes for CO_3^{2-} during carbonate precipitation. The ECF pH decrease in the inhibited corals reduces the relative abundance of the borate species in the ECF. Furthermore, net photosynthesis is reduced in these corals, thereby increasing the [CO_2] in the overlying tissue which is available to diffuse into the ECF. Both these factors reduce the $B(OH)^{4-})/CO_3^{2-}$ of the ECF. However, the reduced ECF pH decreases the CO_2 diffusion gradient and ultimately increases ECF $B(OH)^{4-}/CO_3^{2-}$, and thus skeletal B/Ca.

6B Mechanisms of calcification
Tuesday 10 July, 1745, MR1

Response of carbonic anhydrases to pCO_2 in *Stylophora pistillata*

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Since 1959 and the pioneering work of Goreau, numerous studies revealed the involvement of the enzymes carbonic anhydrases (CAs) in coral physiology. These ubiquitous metalloenzymes are responsible of the reversible hydration of CO_2 into bicarbonate (HCO^{3-}) and proton (H^+). These enzymes are thus highly sensitive to their surrounding pH. Recently, ocean acidification (OA) has been shown to affect mechanisms potentially involving CAs in reef-building corals such as calcification, reproductio and development, acid-base regulation, photosynthesis, respiration, behaviour, and tolerance of other stressors. In this study, we used two previously characterized CAs, as well as mammals' conserved domains to search for other isoforms in a new EST database from the coral *Stylophora pistillata*. We explored the diversity of CA isoforms and identified two new CAs. We then studied their enzymatic activity and expression pattern under different pCO_2 values in order to give an insight into the role of CAs in coral physiology and adaptation.

6B Mechanisms of calcification
Wednesday 11 July, 1035, MR1

Organic matrix characteristics of the calcified skeleton in *Corallium* species

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Corallium species have ecological, cultural, and commercial importance and thus require tools to assist with their identification for both management and trade. The organic matrix (OM) of the skeletons of four *Corallium* species (*C. rubrum, C. konojoi, C. secundum* and *C. elatius*) was examined to provide insight into the biomineralization process and to develop a new tool of identification. The pattern of OM and the set of soluble organic matrix proteins (SOM) in the skeletons were examined by gel electrophoresis. Staining of cross-sections of skeletons showed a common cyclic, concentric pattern of OM during growth. Differences in molecular weight and isoelectric point were observed for proteins in the SOM in different *Corallium* species but not among different populations of *Corallium rubrum*. Immuno-labeling with antibodies against the SOM of *C. rubrum* showed labelling of the OM of the three other *Corallium* species, suggesting the presence of common epitopes.

6B Mechanisms of calcification
Tuesday 10 July, 1715, MR1

What skeleton composition tells us about coral biomineralization

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Some of the key questions outstanding in coral biomineralization studies relate to the source of ions for calcification, the existence of a discrete and isolated calcifying space, and mechanisms for

overcoming kinetic barriers to crystal nucleation and growth. The composition of aragonite crystals that make up coral skeleton provide important insights into these questions, but there is significant ambiguity in the interpretation of these clues because the relative importance of physiological versus physicochemical processes remains a matter of debate. Comparisons of biogenic aragonite with experimentally precipitated, abiogenic aragonite indicate that Rayleigh fractionation has a strong influence on the elemental composition of coral skeleton. The presence of a significant Rayleigh signal is consistent with the hypothesis that seawater is the dominant source of ions used for calcification, and that aragonite precipitation occurs in an isolated or semi-isolated calcifying space. In order to quantitatively explain the composition of coral skeleton, the mass of aragonite precipitated from each 'batch' of calcifying fluid must vary over the course of a year. One possible explanation for this variation is the influence of temperature on the precipitation rate of aragonite, although seasonal variations in the saturation state of the calcifying fluid may also be a contributing factor. The role of organics in the biomineralization process remains unclear. The presence of peptides in the calcifying fluid is known to affect the concentration of Mg in calcite, so the potential exists for the presence of organic molecules to influence the growth rate and/or composition of biogenic aragonite.

6B Mechanisms of calcification
Tuesday 10 July, 1645, MR1

The geochemistry of coral biomineralization

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Fundamental questions in coral biomineralization include: how do ions from seawater reach the coral skeleton, what role do transient phases play during nucleation, and how does calcifying-fluid chemistry control skeletal composition? Using the NanoSIMS we map the uptake dynamics of multiple cations in cultured coral. Our data support direct seawater transport to the site of calcification (tau=30 min - 6 hours) with specific calcium pumping contributing <5% of skeletal calcium. Incorporating these results into a steady-state geochemical model, we can explain skeletal metal/calcium variability. We further show that skeletal Sr/Ca is insensitive to aragonite saturations between 2.7 and 4.9, despite changes in coral growth. These results constrain the factors regulating calcifying fluid acid-base chemistry and suggest that alkalinity pumping targets a specific pH. The interaction between alkalinity-pumping rules and seawater composition explains the full range of Sr/Ca sensitivity to oversaturation and predicts that coral may become increasingly sensitive to ocean acidification below a threshold value. Finally, by comparing calcium isotope ratios from deep-sea coral to inorganically synthesized amorphous calcium carbonate (ACC), we argue that ACC is unlikely to control the composition of centers of calcification. Furthermore, we show that reservoir (Rayleigh) effects can explain skeletal variability in non-traditional stable isotopes like calcium. Interpreted within this model, symmetrical patterns in metal/calcium ratios across individual deep-sea coral imply an evolution in the extent of precipitation during growth, even under constant environmental conditions. Our geochemical approach compliments physiological and biochemical studies towards a mechanistic understanding of biomineralization.

6B Mechanisms of calcification
Tuesday 10 July, 1730, MR1

Light enhanced calcification in *Stylophora pistillata*

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In many zooxanthellae-harbouring corals, calcification rates are known to be higher in the light than in the dark, though the degree of enhancement varies greatly between studies. The origins of this 'light enhanced calcification' though first described over 50 years ago, remain an enigma. Here, we test some of the theories as to the origin of light enhanced calcification by manipulating the products of photosynthesis - providing sugars or oxygen, or by reducing pCO_2. We show that these products of photosynthesis, manipulated in the absence of photosynthesis, can affect calcification in a manner similar to that seen with photosynthesis alone. Though there may be multiple ways by which photosynthesis could enhance calcification, the primary manner by which light enhances calcification appears to be an enhancement of the energy supply potentially available for calcification.

6B Mechanisms of calcification
Tuesday 10 July, 1630, MR1

Skeletal density and microstructure of the calcifying coral *Pocillopora damicornis*

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Skeletal density and microstructure of the calcifying coral is an indicator for coral growth process and their environments. Characteristics of the scleractinian coral skeleton are needed to determine their classification and evolution significance. Furthermore, scleractinian skeletal characteristics are increasingly used to reconstruct

past ocean and climate histories, and thus, to predict future impacts of climate change on coral reefs. To better understand skeletogenesis and mineralogy in extant scleractinian corals, we analyzed the microstructure and composition of common reef-building coral *Pocillopora damicornis* from South China Sea, using Scanning Electron Microscope (SEM) and infrared spectroscopic methods. We also measured skeleton density by using a combination of methods based on the evaluation of buoyant weight. The results revealed that the skeletons were predominantly comprised of aragonite, and fewer with calcite. There were several types of skeletons, which have distinct morphology but share the same basic structures and growth pattern. The occurrence and abundance of cements which combined by secondary aragonite and brucite in the interseptal zone were quite different according to the various habitats. Samples from the open sea were more cement-rich than those from the estuarine influenced area, indicating extensive early marine diagenesis. Samples collected from the open sea were much dense than those of the estuary. We expect that scleractinian corals near the estuary were more fragile and vulnerable to erosion under ocean acidification and other environmental changes.

6B Mechanisms of calcification
Wednesday 11 July, 1030, MR1

Calcification of polyp and accumulation of algae

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A single coral polyp of *Acropora tenuis* created a coral polyp skeleton, while a profusion of unicellular algae of zooxanthellae were accumulated in host polyp tissue. The skeleton formation process was controlled by single polyp growth. At the first main skeletogenesis stage, the 12 branches made of $CaCO_3$ were generated beneath the 12 mesenterial septa at the disk substrate (DST) made of polyp secretion with calcium carbonate right on culture dish. At the second stage, they rose to the basal DST and their edges were fixed by generating a cycle branch. At the later stages, the growth of the 6 sticks from the above circle branch towards the center of coelenteron built up a sheet of 6 branches, as coral polyp formed the six mature tentacles and the six mesenterial septa. The artful polyp skeleton pagoda was built up on the basal DST. A live polyp tightly stayed in a 6 spaces-separated container of ~450 µm in diameter at ~250 µm in height at the top of polyp skeleton. A polyp skeleton formation was performed according to material energetics and Le Chatelier's principal, since the accumulated protons by a series of calcifying reactions ($CaCO_3 + H^+ \rightarrow HCO_3^- + Ca^{2+}$) flew out from polyp skeleton-building local space into polyp tissue. The proton outflow was caused the abnormally low proton concentration. The dynamic stationary effluxes of H^+ and OH^- in the polyp-skeleton system controlled the reversible calcifying reaction in stationary state and vice versa.

6B Mechanisms of calcification
P061

Estimate of calcification responses to environmental stresses

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Responses of coral calcification-which are directly related to coral health- to environmental stresses, have been little studied, except for ocean acidification. In this study, aposymbiotic (without symbionts) and symbiotic primary polyps of the scleractinian coral *Acropora digitifera* were experimentally exposed to several seawater temperatures (27, 29, 31, and 33℃) and salinities (26, 28, 30, 32, 34 ppt) in order to better understand the effects of thermal and freshening stresses on coral calcification from the aspect of coral-algal symbiosis. Calcification rates of symbiotic polyps were higher than those of aposymbiotic polyps in both experiments, except for those reared under the thermal stress above 31℃. Symbiotic polyps demonstrated non-linear calcification responses to increases of temperature and a threshold temperature affecting skeletal growth and bleaching was between 29℃ and 31℃. Aposymbiotic polyps also showed a non-linear increase of calcification according to the increase of temperature with a maximum polyp weight at 31℃, suggesting thermal stress has some damage on coral host itself too. On the other hand, both aposymbiotic and symbiotic polyps showed linear decreases of skeletal growth according to the decrease of salinity. Our results suggest that future global warming will have a negative impact on coral calcification at least at the primary polyp stage. In addition, freshening stress, which would be caused by increase of the intensity of local floods related to future climate change, would certainly decrease coral calcification.

6B Mechanisms of calcification
P062

A spatial model of calcification in scleractinian corals

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Calcification in scleractinian corals is a highly complex process that involves a wide variety of physical, chemical, and biological processes, at several different scales in time and space. Although many of these processes have been studied, coral calcification is still not well understood. Indeed, variations in the relevant environmental conditions, such as pH changes, affect the calcification process and can have severe consequences for the health of the coral holobiont. Therefore, we have constructed a model of calcification in which existing knowledge on the contributing sub-processes is integrated within a mathematical framework. In this model, we have developed a spatial representation of the coral tissue in which we simulate the relevant chemical reactions in the surrounding environment, the transport processes of inorganic carbon and calcium ions through the different cell layers, photosynthesis, respiration, and calcium carbonate precipitation. We model the spatio-temporal changes of the different processes as a set of coupled reaction-diffusion equations together with a new way of modeling transporters. Simulations can be employed to clarify the influence of different individual processes and reaction rates as well as changes in the chemical composition of the surrounding seawater. Our first results showed a good agreement with the available data on calcification. This allowed us to estimate some of the unknown parameters, which we plan to study experimentally. The next step is to use the simulation model to predict the changes in the calcification due to environmental changes.

6B Mechanisms of calcification
Wednesday 11 July, 0930, MR1

Possible acceleration of coral growth by low-intensity pulsed ultrasound irradiation

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Our previous studies showed that the bone turnover of human and some mammals was accelerated by low-intensity pulsed ultrasound irradiation (LIPUS). In a sense, we have assumed that bone turnover of mammals and human resembles coral growth. The objective of this study was to examine effects of LIPUS irradiation on growth of isolated polyps of the coral *Galaxea fascicularis* based on this hypothesis. Thirty polyps isolated from a colony of *G. fascicularis* were divided into three groups, each containing 10 polyps. Polyps of the first groups (group A) were incubated for 1 week without LIPUS irradiation as the control. Second group (group B) polyps were irradiated with LIPUS for 5 min everyday for 1 week. Polyps of third group (group C) were irradiated with LIPUS for 5 min everyday from the third day of incubation. The number of buds formed on isolated polyps were higher in group C polyps than the control (group A), though there was no statistical significance between group B and the control (group A). The present results suggest that LIPUS irradiation accelerates the coral growth under certain condition of the duration and intensity of LIPUS irradiation, like the result related with human and some mammals.

6B Mechanisms of calcification
P063

A new biomineralization model for coral skeleton from mineralogical observations

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Understanding of coral biomineralization is a crucial subject among interdisciplinary fields including material science, biology, geoscience, and paleontology. We observed the biomineralization of a massive coral, *Porites lobata*, collected from Ishigaki Island, Japan. Mineral identification and observation of crystal texture and morphology were carried out from nano to micro meter scale by analytical transmission electron microscope (ATEM). The skeleton consists of so-called 'COC' and 'fibers'. Only a mineral phase of aragonite could be observed in the skeleton. Fibers show bundles of needle-like shape aragonite crystals elongated along crystallographic c-axes of several nm to 1.15 m in width, and several .25 m in length. Periodical contrast at 1-2.25 m intervals could be observed almost perpendicular to the aragonite growth direction. Although the contrast is due to the different sample thickness, these seem to correspond with the growth bands. There is no unique texture related the growth bands, although some papers suggested the bands consisted of the different size distribution of aragonite crystals. Indeed, some of aragonite crystals seem to grow across the growth bands. The crystal size in the skeleton should depend on saturation state of the coral's calcifying fluids. Relatively homogeneous crystal size distribution in the skeleton suggests that the fluids maintain a $CaCO_3$ -supersaturated state during fiber growing. The sample thicknesses-related periodical contrast probably occurred by ion spattering during the sample thinning. Periodical change of chemical composition in aragonite is suggested, because it is known that the strength for ion spattering sometimes depends on chemical composition of minerals.

6B Mechanisms of calcification
P064

Incorporation of gravel into reef coral skeletons

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Reef corals occur in high energy, sediment-rich environments, but entrapped coarse sediment is rarely documented. Many corals have strategies to remove sediment, but some coral morphologies trap coarse sediment particles. Acroporid corals from fringing reefs in Moreton Bay have incorporated pebble-size grains from a substrate of basaltic laterite. Corals from a rocky shore at Bargara, Queensland, have encased mixed gravel sediment from the basaltic substrate, fluvial derived pebbles, and carbonate clasts, including dead *Acropora* branches. Branching corals from Heron Reef, southern GBR, have incorporated gravel-sized grains, including coralline red algae, *Halimeda*, and foraminifers. Some embedded clasts occur at points of fusion between branches within an *Acropora* colony. In this case, the clast may have interfered with the polyps' aversion to grow towards each other, causing fusion when both branches overgrew the clast. In all examples presented here, the coral has deposited a layer of clypeotheca (protective skeleton) to seal itself off from the clast and completely encasing the foreign material before continuing normal growth. This has been documented with a combination of scanning electron microscopy and computer tomography. Embedment of grains within a clypeotheca-lined cavity represents another mechanism of dealing with sediment as a last resort when the grains cannot be removed by any other active or passive means. It also demonstrates a discrete ability to actively modify the skeleton to deal with an environmental stress. Recognition of stress-related coral morphology may aid identification and interpretation of environmental stress events in ancient and living coral reefs.

6B Mechanisms of calcification
Wednesday 11 July, 0945, MR1

Coral calcification in a variable coral reef environment

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As we seek to understand the stresses that corals will face due to ocean acidification, it is necessary to find coral communities that are thriving in regions with variable environmental conditions (e.g., pH). Data from continuous-recording pH sensors deployed in Ofu, American Samoa, show that corals living in back-reef habitats are exposed to variable pH conditions. In Ofu, the back-reef has daily swings in pH of up to 0.56 units; whereas the fore-reef varies by < 0.21 units. During high tide the pH in the back-reef is very close to the pH in the fore-reef due to constant water exchange with the open ocean. However, during low tide the pH in the back-reef is higher during the day, perhaps due to photosynthetic CO_2 consumption, and lower during the night, perhaps due to respiration derived CO_2 evolution. We used back-reef water samples collected across these cycles to test for changes in aragonite saturation in parallel with changes in pH. To investigate if and how corals regulate the expression of calcification genes in response to pH variability and aragonite saturation, *Acropora hyacinthus* RNA was sampled across a series of six high tides and five low tides alongside seawater samples. Coral gene expression is likely to cycle daily, but it is unclear to what degree the environment influences expression patterns. Such data, combining environmental variation and response reactions by corals, will help elucidate the impact that pH variation has on coral physiology and potential growth rate.

6B Mechanisms of calcification
Wednesday 11 July, 1000, MR1

Coral Annual banding occurs in the absence of environmental fluctuations

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When analyzed by X-radiography, slices of skeletons of massive corals show an alternate pattern of one dark band adjacent to one white band, which, taken together, represent growth over one year. Two major environmental factors, light and temperature, are thought to control banding patterns in corals, but a wide range of other factors have also been implicated. Whereas all previous studies have been performed on corals collected from the field, we provide the first results on a living coral colony of *Porites* sp. collected in the field and then maintained in controlled and constant conditions of culture for several years. Since our results show that annual banding persists in aquarium conditions, we can rule out the role of environmental parameters as the primary drivers of annual banding patterns which may result from an endogenous clock.

6B Mechanisms of calcification
P065

Intercolony variation of skeletal compositions tested by a culture experiment

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While the skeleton of corals is considered to be a rich archive of climatic changes in tropical seas

during recent times and the distant past, the potential ambiguity of oxygen isotope thermometers intrinsic in the coral growth and biomineralization process attracts much attention. Here, we study the influence of growth-rates on skeletal oxygen and carbon isotope ratios based on a long-term culture experiment using *Porites australiensis* clone colonies. All colonies exhibited temporal growth rate changes infered from annual cyclicity of skeletal of oxygen isotope ratios over the incubation period of about 6 years. For descriptive purposes, the profiles can be divided into three intervals: a natural stage at the original reef site, a recovery stage after cutting, and a following steady-state growth stage. A gradual change was found in the range of oxygen isotope ratio variation. The temperature-oxygen isotope ratio relationship may vary according to health conditions of the coral colony. This pattern is apparently consistent with growth-rate-related kinetic effects. The oxygen isotope ratios of colonies in the steady-state growth stage showed a negligible influence on intercolony growth rate over a relatively large variation. Positive shifts in interannual trends of carbon isotope ratios for slower-growing corals were found, and can be attributed to the kinetic behavior of calcification reactions.

6B Mechanisms of calcification
P066

Insight on coral skeletal growth from acidification experiments

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Our aim was to use extreme conditions of acidification as a means to better study calcification in corals by analyzing different parameters which are known to be linked to the calcification process. We performed a study where we looked at the effect of acidification on calcification of the scleractinian coral *Stylophora pistillata*. We performed a long-term experiment of one year where we rigorously followed the seawater chemistry under 4 different pH conditions with increasing levels of pCO_2. We looked at the following biological parameters: tissue biomass, morphology and porosity of skeletons, rates of calcium incorporation, and photosynthesis.

6B Mechanisms of calcification
P067

How open is the site of calcification?

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The mechanisms behind the transfer of molecules from the surrounding seawater to the site of coral calcification are not well understood, but are critical for understanding how coral reefs are formed. We present data obtained with the fluorescent dye calcein, which binds to calcium and is incorporated into growing calcium carbonate crystals to determine the permeability of coral cells and tissues. We show results on the electrical resistance of coral tissues in order to better understand the role of tissues in ionic permeability. Our results give information on the trans-epithelial pathway and especially the structure and size of intercellular junctions, together with values of the resistance of the tissues. We discuss the implications of our results for the transport of calcium involved in the calcification process and why molecular characterization of junctions is the next essential step.

6B Mechanisms of calcification
Wednesday 11 July, 1015, MR1

pH regulation at the coral tissue-skeleton interface under ocean acidification

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The emergence of ocean acidification as a threat highlights the importance of pH regulation in coral physiology, particularly in mechanisms linked to coral calcification. Corals elevate extracellular pH (pHe) in the subcalicoblastic medium at the tissue-skeleton interface to promote calcification and also tightly regulate intracellular pH (pH_i) in calcifying cells. Currently, the mechanism underlying the vulnerability of coral calcification to ocean acidification is not clear, but it may be linked to decreases in pH_i and pH_e at the tissue-skeleton interface, and driven by declines in external pH and elevated pCO_2. We investigated this possibility by working with living colonies of *Stylophora pistillata* exposed to a range of elevated pCO_2 treatments over both short-term (days) and long-term (> 1yr) durations. Live tissue imaging of pHi and pHe at the tissue-skeleton interface was performed by confocal microscopy of corals mounted in a seawater perfusion system of known carbonate chemistry. We discuss our findings in the context of additional work that explores rates of calcification of *S. pistillata* exposed to ocean acidification.

6B Mechanisms of calcification
Tuesday 10 July, 1700, MR1

6C Coral physiology & energetics

Influence of seawater temperature increment in Ubhur Creek corals, Jeddah

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The overall annual range of seawater temperature in Obhur Creek, a small embayment on the western coast of Saudi Arabia, was 8.5°C (between 24.5°C and 33°C). Zooxanthellae density showed both species-specific and seasonal variations, e.g. the number of zooxanthellae in *P. damicornis* was slightly higher than in *P. verrucosa*; however, zooxanthellae density was 62% to 66% lower in summer than in winter for both species, respectively. Similarly, the two species differed from each other in the respiration rates of their associated zooxanthellae. The respiration rate for *P. verrucosa* was similar in summer and winter, suggesting compensatory acclimation. In contrast,in *P. damicornis,* the respiration rate was lower in winter than in summer. We speculate that in both species, the difference in zooxanthellae thermal tolerances at 35° C correspond to differences in tolerance of algal genotypes between the two species, thereby resulting in *P. damicornis* bleaching as the process of metabolism exceeds the process of photosynthesis with increased temperature. During the winter season, the metabolic rate was higher for both species due to optimum temperature of the seawater. As a result of the density of zooxanthellae and optimum temperature of the seawater 30°C, the growth of the skeleton of the two coral species was twice as high in winter than in summer.

6C Coral physiology & energetics
Thursday 12 July, 1030, MR1

Autotrophic nitrogen and carbon assimilation among diverse coral taxa

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Much of our understanding of the coral symbiosis is derived from experiments that quantify the amount of oxygen added to or removed from a closed volume of water. When a paired, light-dark treatment is incorporated, the ratio of photosynthesis relative to respiration can be calculated. An organism with a P:R=1 is considered to be producing as much oxygen as it consumes, which can be extrapolated to the equivalent fixation and respiration of carbon. Values above and below 1 are indicative of net autotrophy and net heterotrophy, respectively. Corals and their relatives, having a diversity of colony morphologies, life strategies, and symbiont partners, vary in their reported P:R values, which suggests different nutritional strategies and possibly a gradient from mutualistic to parasitic symbiont partners. In this talk, I will present P:R values from numerous coral taxa, including Caribbean gorgonians, scleractinian, and alcyonarian corals from the Indo-Pacific, but with a modern spin. The addition of isotopically-labeled carbon and nitrogen to the bottle allows for the direct quantification of assimilation of these critical elements, which can be contrasted with P:R. Large variations in P:R were correlated with carbon, but not always nitrogen assimilation. Moreover, there were clear differences between major genera in both P:R and carbon fixation. How symbiont identity affects these metrics will be discussed.

6C Coral physiology & energetics
Thursday 12 July, 0930, MR1

Acquisition and allocation of carbon to lipid classes of bleached and non-bleached Hawaiian corals

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At elevated seawater temperatures, the coral host-endosymbiont relationship can break down, causing a decrease in photoautotrophically derived carbon. Bleached corals must utilize energy reserves or heterotrophically acquired carbon to survive. Here, paired fragments of the Hawaiian corals *Montipora capitata* and *Porites compressa* were reared under ambient (control, 27°C) and elevated (treatment, 30°C) temperatures for 3.5 weeks in outdoor flow-through seawater tanks. All fragments were pulse chase labeled either by incubation in ^{13}C labeled seawater during the day (labeled photoautotrophically acquired carbon), or overnight with ^{13}C-labeled rotifers (labeled heterotrophically acquired carbon), then returned to flow-through tanks. Corals were collected after chase intervals of 4, 16, 24, and 168 hours. Total lipids were extracted from ground whole coral samples and lipids will be separated into major classes (i.e., wax esters, free fatty acids, alcohols, triacylglycerols, diacylglcerols, monoacylglycerols, sterols, and phospholipids) by Thin Layer Chromatography (TLC). Stable isotope analysis (^{13}C) will be run on each lipid class in order to determine if photoautotrophically or heterotrophically acquired carbon is allocated to each lipid class, and how each lipid class is utilized over the chase period within bleached and non-bleached corals. This study will improve our understanding of how carbon from these two sources is assimilated and utilized in bleached and healthy corals.

6C Coral physiology & energetics
Thursday 12 July, 1115, MR1

Effect of ammonium enrichment on the photosynthetic efficiency of corals under thermal stress

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Excessive light and elevated temperatures often induce coral bleaching. It has been shown that particulate food supply helps some corals maintain a high level of photosynthesis during stress events, suggesting that additional nutrients brought by food such as nitrogen, play an essential role in the functioning or the repair of the photosynthetic machinery. This study therefore assessed the effect of ammonium enrichment on pigment concentration, and on the photosynthetic efficiency of photosystems I and II in the coral *Stylophora pistillata* during temperature or light stress. Results obtained first show that under normal culture conditions, addition of 3 µM ammonium for two weeks did not enhance the rates of photosynthesis per skeletal surface area, nor the electron transport rates of the photosystems. However, when corals were submitted to thermal stress (32°C), non-enriched colonies lost almost half of their chlorophyll content, and severely reduced their rates of photosynthesis as well as their PSII's electron transport rate and non-photochemical quenching (NPQ). Conversely, ammonium-enriched colonies maintained their level of chlorophyll, as well as their rates of photosynthesis and photosynthetic efficiency. Moreover, they did not increase the NPQ, showing that energy was not lost as excessive heat. These results show that nitrogen supply helps maintain the level of photosynthetic pigments. They also show a difference in the sensitivity of PS1 and PSII to temperature and light stress.

6C Coral physiology & energetics
Wednesday 11 July, 1755, MR1

Growth and regeneration trade-off in *Acropora muricata*

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Growth and regeneration of artificially induced lesions (20.5 +1.5 mm diameter, 3 mm depth) were monitored in nubbins of the branching coral *Acropora muricata* at two reef flat sites representing contrasting environments (in terms of SST variation, irradiation levels, and water flow), and compared to growth of uninjured nubbins. Photosynthetic efficiency (Fv/Fm) of zooxanthellae was monitored in parallel. Biochemical composition of the holobionts and zooxanthellae densities were determined at the onset of the experiment from a destructively sampled set of nubbins from each site. *A. muricata* regenerates small lesions rapidly, between 80 and 180 days on average. Regeneration rate differed strongly between sites. At the sheltered site, characterized by high temperature variation and irradiance levels, nubbins presented fast growth, high lipid content, chlorophyll a concentration and zooxanthellae densities. At the exposed site, characterized by more stable temperatures and lower irradiation, nubbins grew slower, but demonstrated fast lesion repair as well as higher tissue biomass and protein content. Moreover, a trade-off between growth and regeneration rates was evidenced here. Environmental conditions conducive of high zooxanthellae densities in coral tissues boosted skeletal growth but reduced lesion regeneration rate. Lowered regeneration capacity is likely related to limited availability of energetic and tissular resources, consequences of coral holobionts operating at high levels of photosynthetically derived carbon and energy.

6C Coral physiology & energetics
Thursday 12 July, 1000, MR1

Heterotrophic behavior of *Goniopora lobata* in Hong Kong

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Environmental stresses from elevated temperature, irradiance, and reduced salinity may lead to coral bleaching. Earlier works found heterotrophy to provide 15-35% of daily metabolic demand of healthy corals or to up to 100% of that in bleached corals. Some coral species are able to maintain and restore their energy reserves by increasing their feeding rate during bleaching events. It is thus critical to see whether feeding can provide additional nutrients and energy for coral growth and recovery. In this study, feeding rate of the scleractinian coral *Goniopora lobata* from Hong Kong was examined. Results indicated that *G. lobata* consumed more *Artemia nauplii* during the day (23.1±10.9 ind./polyp/L/hour) than at night (5.04±4.91 ind./polyp/L/hour). Moreover, it was also found that a drop in temperature from 28°C to 24°C increased the feeding rate (19.8±11.4 ind./polyp/L/hour at 28°C; 29.7±8.9 ind./polyp/L/hour at 24°C) and also calcification rate after feeding (1.17±0.05 mg/L/hour at 28°C; 3.02±0.72 mg/L/hour at 24°C). Calcification rate changed with temperature and light intensity. With extensive feeding, coral recovery rate from bleaching could change. A new method was developed to quantify this change using photo-quadrat and computer image analysis. Change in bleaching intensity of the same coral colony can be compared over time. This method can help to systematically monitor coral recovery.

6C Coral physiology & energetics
Wednesday 11 July, 1530, MR1

Effects of pCO_2 and heterotrophy on *Seriatopora caliendrum* spat

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This study investigated the synergistic effects of pCO_2 and heterotrophy on coral physiology during early life stages over ecologically relevant time scales. To our knowledge, it is the first study to successfully feed newly settled recruits to determine whether nutrition-replete conditions alter the response of spat to ocean acidification (OA). Newly settled *Seriatopora caliendrum* spat were exposed to 441 ± 9 µatm (ambient) and high 819 ± 19 (high) µatm pCO_2 for 15 d. Half of the spat from each treatment were fed freshly hatched *Artemia* spp. every second day for two hours. Spat respiration and survival was recorded every second day, while calcification, biomass, and *Symbiodinium* densities were measured on days 7 and 15. A strong interactive effect of pCO_2 and heterotrophy for *Symbiodinium* density revealed that feeding at ambient pCO_2 stimulated algal densities, but that high pCO_2 prevented this effect. Changes in symbiont densities did not correspond to differences in calcification, which was similar across all treatment. Initially, elevated pCO_2 depressed *S. caliendrum* respiration, although the effect was mitigated over time so that respiration was similar in both pCO_2 treatments by day 15. Predictably, fed spat demonstrated higher rates of respiration and increased biomass compared to non-fed spat. Together, these results demonstrate that while elevated pCO_2 can negatively impact the early life stage of coral, the effect may be less severe over longer exposure periods. Evidence that newly settled recruits are resistant to elevated pCO_2 suggests that constitutive mechanisms may be available to resist negative aspects of OA.

6C Coral physiology & energetics
Wednesday 11 July, 1730, MR1

Elevated nutrient levels and stability of the coral-dinoflagellate symbiosis

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As concerns of rising sea surface temperatures and ocean acidification come to the forefront of coral reef science, it must be understood how these stressors will interact with local factors which lead to reef degradation. The mechanism whereby elevated levels of dissolved inorganic nutrients directly degrade coral health remains unclear. There is disagreement among hypotheses which suggest direct influence on the process of calcification and those suggesting degradation through a destabilization of the coral-dinoflagellate symbiosis. Coral incubations are being conducted to elucidate this mechanism and to understand the potential of synergistic responses to elevated NO_3^{2-}, NH_4^+, and PO_4^{2-} in combination with elevated temperature and pCO_2. Stable isotopes are utilized as a tool to understand the sources and fates of carbon and nitrogen within the coral dinoflagellate symbiosis in *Acropora cervicornis* and *Pocillopora damicornis*. Several parameters are measured to assess responses of coral health to elevated stressors (calcification, linear extension, photosynthesis, C:N ratios, symbiont density and diversity). Preliminary data suggest that elevated levels of inorganic nitrogen degrade corals directly through alteration of the symbiotic relationship between coral host and dinoflagellate algae. Photosynthetically derived energy allocated to the coral host decreases, ultimately resulting in decreased rates of coral growth. The behavior of the symbiosis under multiple stressors is currently under investigation.

6C Coral physiology & energetics
Wednesday 11 July, 1215, MR1

Prokaryote vs. eukaryote biosynthesis of mycosporines and mycosporine-like amino acids

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The assumption that coral/algal mycosporine-like amino acids (MAAs) originate from the shikimic acid pathway stems from specific uptake of the shikimate intermediate [U-^{14}C]3-dehydroquinic acid (DHQ) in biosynthesis of the MAA-related, fungal mycosporines, a pathway demonstrated empirically in the cyanobacterium *Chlorogloeopsis* sp. Recently, MAA biosynthesis has been elucidated in the cyanobacteria *Anabaena* and *Nostoc*, which utilise the precursor sedoheptulose 7-phosphate (SH 7-P) derived from the pentose phosphate pathway rather than 3-deoxy-D-arabinoheptulosinate 7-phosphate (DAHP) of the shikimate pathway. The key enzyme of the pentose phosphate pathway, 2-epi-5-epi-valiolone synthase (EVS), is strikingly similar to 3-dehydroquinate synthase (DHQS) of the shikimate pathway, both enzymes being homologs of the same cyclase superfamily. We now reveal UV-induction of MAA biosynthesis in an EVS-null mutant, which implicates the existence of parallel MAA biosynthetic pathways in *Anabaena*. EVS encoding genes were found also in the coral *Acropora digitifera* and the sea anemone *Nematostella vectensis*, yet the anemone does not appear to produce MAAs. Although not validated experimentally, we have identified by UV induction hypothetical genes for MAA biosynthesis in the

holobiome of the coral *Acropora microphthalma*. Post-DHQ biosynthetic enzymes appear encoded in the coral DNA, which is exceptional because its dinoflagellate endosymbiont does not produce MAAs in culture. We posit that acroporid corals have acquired MAA biosynthetic genes by transfer from their dinoflagellate partner followed by deletion from its source genome in a pathway yet to be validated in an anthozoan.

6C Coral physiology & energetics
Wednesday 11 July, 1515, MR1

Seasonal upwelling stimulates primary production of Colombian Caribbean coral reefs

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Abiotic factors like light intensity and water temperature influence coral reef productivity. In Tayrona National Natural Park, located in the Colombian Caribbean, these factors are subject to high temporal variability due to seasonal coastal upwelling events. This offers the unique opportunity to assess these effects on the coral reef ecosystem service productivity under in-situ conditions in space and time. After identifying the dominant functional groups of primary producers (scleractinian corals, macroalgae, microphytobenthos, crustose coralline algae, and algal turfs) at upwelling-exposed and -sheltered sites of Gayraca Bay, we performed incubation experiments to quantify oxygen production rates of the different groups. The experiments were conducted before and after the upwelling event in 2011. First, spatial findings revealed macroalgae as most efficient net oxygen producer and microphytobenthos as most efficient gross oxygen producers. Additionally, both of these functional groups showed significantly different oxygen production rates at the two sites. Related to the seafloor area, overall benthic oxygen production rates were similar at the different sites, but significant differences were detected within most functional groups between the sites for net (corals, crustose coralline algae, and macroalgae) and gross oxygen production (corals, crustose coralline algae, and microphytobenthos). These findings suggest a high spatial variability of benthic primary production within the bay, despite similar overall production and indicate high plasticity of coral reef productivity. Future studies will focus on upwelling-induced temporal variability of benthic primary production in this region.

6C Coral physiology & energetics
Wednesday 11 July, 1750, MR1

Role of host and symbionts in coral alkaline phosphatase activity

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Dissolved organic phosphorus is a significant nutrient source for corals, yet few studies have investigated its uptake in tropical and temperate corals. Depletion experiments of para-nitrophenyl phosphate from enriched seawater allowed us to compare the alkaline phosphatase activity (APA) in various corals and their symbiotic zooxanthellae, with the aim of gaining better knowledge on the roles of the host and the symbionts in phosphorus uptake. We measured the kinetics parameters of the *Stylophora pistillata* holobiont and its freshly isolated zooxanthellae (FIZ). We compared the host and symbiont APA in six species of tropical (*S. pistillata*, *Pocillopora damicornis, Galaxea fascicularis*, *Pavona cactus*) and temperate (*Occulina patagonica, Cladocora caespitosa*) corals in symbiosis with three different *Symbiodinium* clades, and compared the APA of those corals with that of the asymbiotic tropical coral *Tubastrea* sp. We also assessed the impacts of light, bleaching, and starvation on the APA of *S. pistillata* and its FIZ. Results showed that in all tested corals, dissolved organic phosphorus uptake was more driven by the host than by the zooxanthellae in hospite, although APA was enhanced by light, and decreased when corals were bleached. Particulate feeding of the host significantly improved APA in bleached corals. These preliminary results demonstratethe importance of the host in the uptake of organic nutrients.

6C Coral physiology & energetics
P069

A survey into physiological differences of *Symbiodinium*

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Zooxanthellae, symbiotic dinoflagellates belonging to the genus *Symbiodinium*, are found in many tropical and subtropical marine invertebrates, such as reef-building corals, sea anemones, and jellyfish. The symbiotic association between corals and zooxanthellae is a main contributing factor to the success of reef-building corals. Molecular genetic studies revealed a rich diversity of *Symbiodinium* species, and showed that different coral species host different species of zooxanthellae, all of them demonstrating distinct characteristics. It is thought that different types of zooxanthellae display different physiological characteristics towards the same physiological condition. Much research focuses on the responses of zooxanthellae to thermal or irradiance stress. Here, we look at both factors and

the combination thereof. More specifically, we investigate the photosynthetic performance and respiratory demands of *Symbiodinium* under varying temperature and light schemes. Using pulse amplitude modulation (PAM) fluorometry combined with microsensor measurements, we aim to understand differences and similarities between different algal species, and how those translate into the potential to deal with a diverse set of temperature and light regimes. The results contribute to our understanding of zooxanthellate physiology, and might help understand why some species thrive and others decline in a rapidly changing world.

6C Coral physiology & energetics
Thursday 12 July, 1040, MR1

The metabolome of *Symbiodinium* phylotypes and their coral hosts

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Symbiodinium spp. live freely in the water column and are in symbiosis with a number of marine invertebrates, such as coral, giant clams, and anemones that are predominantly found in waters with low nutrient concentration and plankton densities. Invertebrates have formed this symbiotic relationship with *Symbiodinium* in order to gain a competitive advantage through increased fitness, allowing the bilateral exchange of metabolites, including the production of metabolites that are not formed by either organism separately. Scleractinian (hard) coral and their relationship with *Symbiodinium* spp. are of particular interest to researchers, due to the fundamental role that scleractinian coral have played in the formation and maintenance of coral reefs and their susceptibility to climate change. Metabolomics is an emerging technique that is able to report on the molecular status of an organism by providing 'snapshots' of the metabolome over time. In fact, time is critical to the coral metabolome due to its dynamic nature, where changes in the environment will present themselves as measurable changes in the metabolome, usually within seconds. Furthermore, metabolomics is able to provide novel datasets of the symbiont-holobiont metabolism in response to selective pressures. To date, no research has analysed the complex metabolome of the coral holobiont, yet it is a vital element in understanding the organisms response to environmental stress. Here, we present the fundamental concepts of metabolomics and the results of a newly developed sample handling and extraction method for the metabolome analysis of healthy and stressed (i.e., via increased temperature and [CO_2]) *Acropora aspera*.

6C Coral physiology & energetics
Wednesday 11 July, 1230, MR1

What combinations of coral species and *Symbiodinium* are more resilient to repetitive bleaching?

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Mass bleaching events are expected to increase in frequency in the coming decades. Yet, how repeated bleaching stress impacts coral physiology, survival, and resilience is unknown. Here, *Symbiodinium* type and host physiological traits (lipids, protein, carbohydrates, calcification, feeding, and stable isotopes) were measured in bleached, repeatedly bleached, and control fragments of *Porites astreoides*, *Porites divaricata*, and *Montastraea faveolata* corals. There was no change in *Symbiodinium* type within *P. astreoides* after single or repeated bleaching, yet host physiology declined only with repeated bleaching. Thus, this coral appears to be resilient to single bleaching but has low resilience to repeated bleaching. Despite a shift towards the more thermally tolerant A4 *Symbiodinium* after single bleaching, *P. divaricata* host physiology declined. However with repeated bleaching, *Symbiodinium* in *P. divaricata* shifted to include both C47 and A4, with no decline in host physiology. Thus, resilience was higher in the surviving repetitively bleached *P. divaricata* than in the singly bleached fragments. Finally, although the thermally tolerant *Symbiodinium* D1a, as well as A3 and A13 became prevalent in many of the treated *M. faveolata* after single and repeat bleaching, host physiology declined more after repeated bleaching. Thus, *M. faveolata* is moderately resilient to single bleaching and has low resilience to repeated bleaching. Overall, the combination of coral and *Symbiodinium* species that imparted resilience after single bleaching did not predict resilience to repeated bleaching. Consequently, the species composition of future reefs could be quite different than that expected based on previous findings from single bleaching experiments alone.

6C Coral physiology & energetics
Wednesday 11 July, 1115, MR1

Linking parental energetics and larval fitness in Caribbean coral

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Metrics such as benthic cover and incidence of disease or bleaching provide useful reference points for understanding the status of coral communities, yet these evaluators often fail to assess the underlying condition of corals that lack visual signs of deterioration. Therefore, we sought to understand whether energy reserves in the form of storage lipids (wax esters and triacylglycerol) are disparate between conspecifics living on degraded vs. non-degraded reefs (as defined by traditional metrics). We measured lipid class composition of four common Caribbean species (*Montastraea annularis, Acropora palmata, Siderea radians,* and *A. humilis*) at three sites within degraded and non-degraded regions of Curaçao. Total storage lipid content was less at degraded sites in all species except *S. radians*, and most dramatically, storage lipids in the endangered *A. palmata* were reduced by 42%. In order to assess the long-term implications of disparate adult energetic status, we collected eggs/larvae from the above four species on a per colony basis to determine if there is a relationship between larval and parental lipid content as an index of reproductive investment. We then evaluated whether larval size and/or lipid content affected fitness, measured as survival; settlement; and post-settlement survival. Links between community degradation, parental energy status, and larval fitness show that non-degraded coral communities play a disproportionately large role in the success of future generations.

6C Coral physiology & energetics
Thursday 12 July, 1200, MR1

Photoprotection through antenna complex dissociation in scleractinian coral symbionts

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Elevated temperatures in combination with high irradiance are known to cause bleaching events in scleractinian corals that are characterised by damage to photosystem II (PSII). Non-photochemical quenching (NPQ) mechanisms of the symbiont can reduce the excitation pressure impinging upon PSII. In the bleaching sensitive species, *Acropora millepora* and *Pocillopora damicornis*, high light alone induced photoprotection through xanthophyll pigment cycling, increased content of the antioxidant carotenoid β-carotene, as well as the dissociation of the light harvesting complexes (LHCs). Evidence suggests both the membrane-bound chlorophyll *a* - chlorophyll c_2 - peridinin-protein (acpPC) complexes and peripheral peridinin-chlorophyll-protein (PCP) complexes disconnected from PSII, with acpPC complexes potentially showing a state transition response with redistribution towards photosystem I (PSI) to reduce PSII over-excitation. Exposure to thermal stress as well as high light promoted xanthophyll de-epoxidation and increased β-carotene content, although it did not influence LHC dissociation, indicating light, rather than temperature, controls LHC dissociation. In the bleaching tolerant species, *Pavona decussata*, xanthophyll cycling along with PCP dissociation was sufficient to prevent PSII photoinhibition, regardless of treatment temperature. Therefore, we propose that coral bleaching in thermally-sensitive species is caused by insufficient photoprotection under high irradiance and elevated temperature, despite the up-regulation of a suite of NPQ mechanisms.

6C Coral physiology & energetics
Wednesday 11 July, 1200, MR1

Coral micropropagation: lessons learned and possible uses

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Numerous studies have shown that the developmental plasticity of corals results in processes of tissue remodeling to occur naturally following environmental stress. In our lab, we harnessed this innate capacity to produce lines of clonally-derived coral micropropagates for a variety of uses. We found that explantation of minute tissue fragments from adult coral colonies or polyps, and maintenance under properly controlled conditions of temperature light and water motion, give rise to micropropagates that developed into whole colonies or individuals. Using histology, immunohistochemistry, and transmission electron microscopy we followed the cellular processes occurring during reorganization of coral tissues following explantation from the mother colony and showed that they re-differentiate into fully functioning polyps. These processes include cellular degradation and programmed cell death, cell migration, proliferation, and de novo differentiation. These processes are comparative to those that occur during natural embryological developmental and regeneration processes, indicating that the coral tissues retain their 'totipotent state'. In addition, we showed that explant morphology can be altered by manipulating environmental parameters. We further showed that multigenerational explantation (i.e., re-explantation of explant-derived micropropagates) resulted in additional polyp development, indicating that there is a resetting of aging processes. The miniature size of the micropropagates and ease of manipulation of this process allows the production and long-term maintenance of clonally derived lines of these micropropagates for numerous research purposes, thereby developing coral model lines that are amenable to comparative and collaborative studies worldwide.

6C Coral physiology & energetics
Wednesday 11 July, 1715, MR1

Photoprotection of *Symbiodinium* differs between two scleractinian corals

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High solar irradiance is a significant environmental factor that is associated with coral bleaching and may induce severe photodamage to the photosystem II (PSII) of *Symbiodium* sp. If photodamage is not minimized or counteracted by photoprotective and photorepair processes, exposure of corals to high irradiance can result in photoinhibition of photosynthesis and consequently in coral bleaching. In order to assess the capacity for photoprotection and photorepair, we investigated photosynthetic performance of *Symbiodinium* sp. in a bleaching 'sensitive' coral (*Pocillopara damicornis*) and a bleaching 'tolerant' coral (*Pavona decussata*), subjected to full natural radiation for 4 days. Gross photoinhibiton was simulated by blocking de novo synthesis of PSII D1 protein. No significant reductions in maximum photochemical efficiency of PSII (Fv/Fm) could be detected in untreated corals at night-time, demonstrating that both corals were similarly capable to replace photodamaged photosystems. Nevertheless, a significant down-regulation of effective photochemical efficiency of PSII (AF/Fm') at solar noon was found, which was more pronounced in *P. damicornis* compared to *P. decussata*. Furthermore, *P. damicornis* revealed a 1.5 times higher ratio of photoprotective to light-harvesting pigments than *P. decussata*, along with a higher de-epoxidation state the xanthophyll pool size. Results indicate that symbionts in *P. decussata* and *P. damicornis* might experience different in-situ light regimes, which is likely due to inherent tissue properties and symbiont densities. In an auxiliary experiment, high light exposed corals were supplied with freshly caught zooplankton supplemented with *Artemia nauplii* for 4 days, which, however, did not influenced photosynthetic activities or pigment concentrations.

6C Coral physiology & energetics
Wednesday 11 July, 1145, MR1

Feeding activity of coral *Pocillopora damicornis* in the Gulf of Thailand

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In this study, the feeding rates of coral *Pocillopora damicornis* collected at Samae San Area, Gulf of Thailand, were investigated. Coral fragments 1-2 cm in length (approximately 80 polyps) were attached on substrates by using a super glue, and then fragments were placed in a 1 L glass aquarium. Newly hatched *Artemia salina* was used as coral food. Food was given to corals in 3 different treatments, either early in the morning (0600), late in the evening (1800), or both in the morning and evening (0600 and 1800). There were 5 replicates in each treatment. At the beginning of the experiments, 200 *A. salina* was added in each replicate, and the remaining food eaten by the corals was counted at h 12 after food was given each time. The experiment was run for 6 days. The results showed that there were significant differences on the feeding rates of corals between treatments ($p < 0.05$). When food was given once a day, corals consumed more *A. salina* in the morning (2.19±0.11 individuals/polyp) than in the evening (1.52±0.05 individuals/polyp). In addition, when corals were given food twice a day, the results showed that corals consumed 1.82±0.12 individuals of *Artemia* /polyp/day, and they preferred to feed in the morning. Thus, *P. damicornis* preferred to feed on zooplanktons in the morning. This finding can be used as an aid for coral rearing in Thailand.

6C Coral physiology & energetics
P070

Characterization of Photosystem II electron transport in cultured *Symbiodinium*

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Previous studies have indicated the Photosystem II (PSII) reaction centre and its oxygen-evolving complex as potential sites of impact during mass coral bleaching. We carried out flash-induced chlorophyll fluorescence measurements in the absence of inhibitors, showing rate parameters faster, especially in case of the recombination phase, than those typically observed and in the presence of DCMU. The fluorescence characteristics were also measured in intact corals. PSII functioning in cultured *Symbiodinium* was further characterized by flash-induced oxygen evolution measurements. We conclude that cultured *Symbiodinium* cells have similar characteristics to those of aerated intact corals. The fast charge recombination may serve as a photoprotective mechanism under high light conditions as demonstrated for cyanobacteria, and also lead to the highly dampened flash pattern of oxygen evolution. The PSII reaction center complex contains an alternative donor component that can be re-reduced in a few minutes. This alternative donor is most likely Tyr-D, whose stability in the oxidized form is significantly less than in other organisms where its re-reduction takes place in 15-20 min. Microaerobic environment induces oscillatory behavior of fluorescence relaxation in cultured *Symbiodinium* - an effect also observed in

intact corals, and likely to be related to the earlier reported spontaneous hypoxia and concomitant reduction of the PQ pool of coral embedded zooxanthellae in the dark. The effects of inhibitors has also been studied and the results will be reviewed in terms of the likely primary lesion to photosynthesis during coral beaching.

6C Coral physiology & energetics
Wednesday 11 July, 1400, MR1

Coral imaging: distribution of zooxanthellae, photosynthetic activity, and fluorescent proteins

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Research on photosynthetic corals has been highly focused on the symbiosis between the coral host and its dinoflagellate endosymbionts (the zooxanthellae). While molecular methods are becoming increasingly popular, the use of imaging tools is still relatively scarce, particularly for macroscopic analysis. Despite the potential of imaging techniques for assessing the spatial heterogeneity of key parameters of coral photobiology, (e.g. photosynthetic activity, zooxanthellae content, or fluorescent proteins) to our best knowledge, no study has attempted to simultaneous map these three features simultaneously. This study explores the possibility to simultaneously quantify in vivo the 2-D distribution of photosynthetic activity, zooxanthellae, and fluorescent proteins. An imaging Pulse Amplitude Modulated fluorometer, modified to use monochromatic excitation light of different wavelengths and the selective detection of short band spectra using different bandpass filters, was used to sequentially excite and quantify photophysiological parameters. These parameters included chlorophyll a variable fluorescence (calculating maximum and effective quantum yield of photosystem II), content of chlorophyll *a* (estimating zooxanthellae density) and fluorescent proteins (estimating their relative content). The use of this imaging system was illustrated by mapping the distribution of these photophysiological parameters both horizontally, across the surface of corals, as well as vertically, throughout a longitudinal section of soft corals. The results allowed for the detailed study of the spatial relationship between photosynthetic activity, including photoprotection efficiency against photoinhibition, and zooxanthellae and fluorescent proteins content within the coral tissues.

6C Coral physiology & energetics
Wednesday 11 July, 1745, MR1

DOC fluxes in healthy and bleached *Montastraea faveolata, Porites astreiodes,* and *Porites divaricata* corals

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Dissolved organic carbon (DOC) represents a large pool of fixed carbon on coral reefs, and could represent a significant heterotrophic carbon source to corals. Here, the DOC flux rates were determined for 3 species of healthy (ambient 30°C) and bleached (31°C) Caribbean corals: *Montastraea faveolata, Porites astreoides,* and *Porites divaricata*. After 2.5 weeks in experimental tanks, individual corals were placed into a closed-top chamber with internal stirring and incubated for 1.5 hours during the day and night. Filtered aliquots of 30 mL were taken at the beginning of and after the incubation and analyzed for DOC. Healthy *M. faveolata* and *P. astreoides* produced DOC. However, when bleached, *M. faveolata* corals had net uptakes of DOC, signifying that DOC was a heterotrophic carbon source for this species. *P. divaricata* were net consumers of DOC, both when healthy and when bleached, indicating that DOC is a source of heterotrophic carbon for this species irrespective of its health status. Overall, this research suggests DOC can be an important source of fixed carbon to bleached corals and may help corals recover from bleaching. DOC fluxes for repeat bleached corals will be presented as well.

6C Coral physiology & energetics
Thursday 12 July, 1130, MR1

Effect of environmental parameters on scleractinian coral nutrition

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Although it is widely accepted that photoautotrophic processes provide the primary source of fixed carbon and nitrogen for scleractinian corals, the relative contribution of heterotrophy to their diet remain poorly understood. The aim of this study was to investigate the relative contribution of heterotrophy versus autotrophy in scleractinian corals inhabiting contrasted fringing reefs in the lagoon of Moorea (Society Island, French Polynesia). The study was conducted during both the rainy and the dry seasons. Twelve species of scleractinian corals from 7 genera were sampled once per season and at 3 sites of Moorea: Vaiare, Maharepa and Tihaura. The carbon (13C) and

nitrogen (15N) stable isotope method has been used to elucidate trophic transfers. Host tissues and zooxanthellae cells were separated by centrifugation and 13C and 15N analysis are currently under process on both fractions. Water parameters such as salinity, temperature, pH, dissolved oxygen, nutrients, chlorophyll a and suspended particulate matter were also monitored on the three sites. Our first data showed that Vaiare is a site with high concentrations of suspended particulate organic and inorganic matter and nutrients ($NH4^+$, NO_2, PO_4^{2-}, $SI(OH)_4$) while Maharepa and Tihaura have intermediary levels of sedimentation and nutrients. Moreover, our results provide evidence that density of symbiotic zooxanthellae and chlorophyll *a* concentration in coral tissues varies between species and among sites. However, all the species did not show the same response to different local environmental conditions. Stable isotope analysis will be discussed in terms of trophic abilities of corals in contrasted environments.

6C Coral physiology & energetics
Wednesday 11 July, 1415, MR1

Symbiodinium carbon limitation: parameters and feedback with thermal stress

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The symbiotic algae of corals, genus *Symbiodinium*, exhibit many unusual photosynthetic features, including the utilization of a Form II ribulose bisphosphate carboxylase/oxygenase (Rubisco) that is unique among eukaryotes. This enzyme is responsible for photosynthetic carbon fixation and has a low affinity for CO_2 relative to the Form I Rubisco of land plants, yet is the metabolic foundation of extremely productive coral reef ecosystems. *Symbiodinium* cells within coral tissue exist in very dense populations in a highly energetic microenvironment typified by high temperatures, irradiances, and oxygen concentrations and they depend upon their host for an adequate supply of dissolved inorganic carbon for photosynthesis. It has been hypothesized that disruption of this carbon supply, e.g. by thermal stress or disease, may increase the susceptibility of the symbionts to photodamage and/or reactive oxygen species production, reinforcing a positive feedback loop of holobiont decline. We report the effects of thermal stress and carbon limitation on photoinhibition and the simultaneous photosynthetic CO_2/O_2 fluxes of multiple *Symbiodinium* phylotypes in culture utilizing a novel apparatus comprised of an infrared gas analyzer and oxygen electrode paired with a pulse amplitude modulated fluorometer. Further investigations determine the effects of thermal stress and pH on the carbon compensation point, half saturation constant, and ratio of bicarbonate/CO_2 uptake using membrane inlet mass spectrometry. *Symbiodinium* phylotypes differ in their thermal optima and exhibit pronounced induction of nonphotochemical quenching under carbon limitation. Together these experiments serve to better characterize *Symbiodinium* carbon requirements and their potential responses to thermal bleaching events.

6C Coral physiology & energetics
Wednesday 11 July, 1130, MR1

Coral auto- and heterotrophic responses to large amplitude internal waves

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To explore potential acclimatization mechanisms of reef corals to the frequent and intense disturbances caused by Large Amplitude Internal Waves (LAIW), the prey capture disposition and photosynthetic performance (Fv/Fm) of corals were investigated in relation to changes in the water temperature, pH, flow speed, and food availability. LAIW simulation studies were carried out under controlled laboratory conditions using *Porites lutea* as a model organism. Cold water stress caused an immediate retraction of the coral polyps into their calyxes, particularly when also the pH was altered, whereas the pH alone caused the expansion of the polyps. Moreover, the life history of the colonies played a crucial role in their responses, where corals previously exposed to LAIW in the field showed lower retraction levels than LAIW-inexperienced controls, suggesting acclimatization. Although the presence of food stimulated polyp expansion, we found an overriding effect of the thermal stress causing polyp contraction. Low temperature did not seem to influence the photosynthetic yield, but LAIW-experienced corals showed higher performance than LAIW-inexperienced controls and were able to sustain those high levels in long term experiments, relative to the controls. This study suggests that LAIW invoke phenotypic acclimations that may be important in strengthening their metabolic performance and resistance to stressors at different scales.

6C Coral physiology & energetics
Wednesday 11 July, 1630, MR1

Impact of environmental changes on the nutritional function of cnidaria-dinoflagellate symbiosis

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Reef-building corals harbor a diversity of dinoflagellate symbionts and their metabolic activities are fundamental to the functioning of coral reef ecosystems. It is now widely acknowledged that climate change will disturb the dynamics of this symbiosis, causing an increase in the extent and the severity of mass bleaching events in the near future. However, the effect of a rapidly changing environment on the energy and nutrient acquisition and metabolic requirements of coral reefs remains unclear and yet is an essential component of the functional sustainability of reefs. Here, we report on preliminary studies specifically focused on the ability of cnidarian hosts associated with different dinoflagellate symbionts to acquire and retain essential nutrients (carbon and nitrogen) and exchange metabolic compounds under a range of environmental change scenarios, including warming, ocean acidification, and increase in nutrient loads.

6C Coral physiology & energetics
Thursday 12 July, 0945, MR1

Cellular basis of thermal tolerance in Lord Howe Island corals

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The world's southernmost coral reef is located at Lord Howe Island (LHI, 31° 33'S; 159° 4'E). Corals at this high-latitude site associate with a diverse range of *Symbiodinium* types, whose photochemical capabilities are adapted to varying and often extreme temperatures. We studied the effect of experimentally elevated (29°C) and decreased (15°C) thermal conditions on chlorophyll fluorescence parameters, bleaching, and xanthophyll cycling of 4 common LHI coral-*Symbiodinium* associations: *Pocillopora damicornis* predominantly hosting *Symbiodinium* ITS-2 types C100 and C118, *Acropora* sp., and *Porites heronensis*. The latter two generally host distinct molecular symbiont types of clade C. Exposure to 15 °C led to a stronger decline of maximum quantum yield (Fv/Fm) in *P. damicornis* C118 than *P. damicornis* C100, *Acropora* sp., and *P. heronensis* (80% compared to 20 - 36% decline). Exposure to 29 °C resulted in a strong Fv/Fm decline, severe bleaching, and upregulated xanthophyll cycling in *P. damicornis* C100 when compared to the other associations (Fv/Fm declined 87% compared to 22 - 30%). At both temperatures, *P. heronensis* showed a moderate (20 - 30%) decline in Fv/Fm, moderate (30 - 60%) loss of pigments, and increased xanthophyll cycling. These data do not indicate a clear link between thermal tolerance and xanthophyll cycling. Analysis of the fatty acid composition of the thylakoid membranes will elucidate the role of fatty acid biosynthesis in regulating photochemical performance when temperatures change. These results and other protective mechanisms in *Symbiodinium* that might contribute to the success of corals at Lord Howe will be discussed.

6C Coral physiology & energetics
Thursday 12 July, 1215, MR1

Alternate methods of estimating light respiration in two species of corals

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Corals are complex symbiotic systems with several respiratory compartments and two photosynthetic compartments, the zooxanthellae of the cnidarian endoderm, and the endolithic microalgae inside the skeleton. How these interact within the coral holobiont under different light regimes is also a complex issue. We have studied gaseous exchange in corals using two approaches: i) a photosynthetron (PS) with unidirectional light in which O_2 exchange, CO_2 exchange and pH could be monitored, together with pulse amplitude modulation (PAM) fluorometry as a proxy for net photosynthesis, and ii) oxygen microelectrodes, both at the coral surface to monitor O_2 flux and by rapid light-dark shifts within the tissue, to estimate light respiration. In the branching coral *Pocillopora damicornis*, PS results indicate an increase in oxygen efflux and a light-driven carbon uptake, up to intermediate light intensities, followed by a flat response at higher intensities. In the foliaceous coral *Pavona decussata*, O_2 and CO_2 exchange showed little correlation with light intensity. Protein biomass concentrations were significantly higher for *P. decussata*, resulting in a greater amount of respiration and suggesting this species has a greater internal metabolic carbon pool. In contrast to the PS results, light respiration increased with light intensity for both species when measured with microsensors. Whereas net oxygen exchange at the coral surfaces showed an asymptotic relationship to light intensity, as would be expected. These results will be discussed in terms of the various carbon and oxygen pools available to the photosynthetic and respiratory compartments in response to incident irradiance.

6C Coral physiology & energetics
Wednesday 11 July, 1430, MR1

Seasonal shift from autotrophy to heterotrophy in a temperate symbiotic coral *Cladocora caespitosa*

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We aimed to investigate the extent of auto-and heterotrophy in colonies of the Mediterranean symbiotic coral *Cladocora caespitosa*, and to determine the coral potential food sources. This species forms large banks in the North Mediterranean Sea and therefore serves as a model of temperate symbioses. The carbon and nitrogen isotopic composition of the zooxanthellae, animal tissue, symbiotic association, and potential food sources (plankton, particulate organic matter in the seawater and in the sediment) were measured in winter and summer. Our results demonstrated a strong seasonal difference in the signature of the zooxanthellae and host tissue. In winter, the ^{13}C signature of the host significantly decreased to -28‰, and was comparable to the signature of the external food sources (-24‰ to -25‰), suggesting a large dependence of *C. caespitosa* on these sources during this season. There was also 3‰enrichment between the ^{15}N signatures of the food (4-5‰) and the signature of the symbiotic association (7-8‰), suggesting that nitrogen was also acquired through feeding. Conversely, in summer, ^{13}C signatures of the coral host and zooxanthellae were similar (-17‰) and very different from the signature of the food sources (-21‰ to -25‰), suggesting that corals were relying on autotrophy for the acquisition of carbon. ^{15}N values also suggested that nitrogen was not acquired through feeding. These results confirm previous observations that temperate corals derive a large fraction of their energy from heterotrophic feeding in winter.

6C Coral physiology & energetics
Wednesday 11 July, 1500, MR1

Alternative photosynthetic electron pathways in symbiotic dinoflagellates of reef-building corals

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The high productivity of coral reef ecosystems is largely attributed to the mutualistic symbiosis between reef-building corals and their intracellular dinoflagellate in the genus *Symbiodinium*. In the natural environment, the holobiont has to cope with significant daily variations in light intensities that sometimes exceed *Symbiodinium* photosynthetic capacity. Fortunately, photosynthetic organisms possess regulatory features that help to ensure that high light intensities can be endured without the accumulation of photodamage. Thus, the regulation of photosynthesis can be viewed as a dynamic balance between photosynthetic efficiency (photochemical quenching) and photoprotection processes (i.e., non-photochemical quenching). In addition to the linear electron flow (LEF) operating during oxygenic photosynthesis, alternative electron flows (AEF) have been widely described in higher plants and microalgae, but not in *Symbiodinium*. Here, we aimed to highlight the existence of the Mehler ascorbate peroxidase pathway (reduction of oxygen by PSI), chlororespiration (oxidation by molecular O_2 of the PQ pool), and cyclic electron flow around PSI. We report that the presence of particular AEF and/or their amplitude vary among clads. These processes could play a key role under particular environmental conditions when sinks for photosynthetic electrons are scarce. Indeed, they could sustain significant levels of photosynthetic electron flux by initiating the pH formation and of NPQ, regulating the ratio of ATP/NADPH to match the requirements of carbon reduction and reducing the excitation pressure over the photosynthetic apparatus.

6C Coral physiology & energetics
Wednesday 11 July, 1250, MR1

***Sarcophyton glaucum* and *Sinularia flexibilis* photosynthesis under different light regimes**

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Light is one of the most important abiotic factors influencing corals photosynthetic performance and it varies across various scales, from large depth gradients to small differences within a coral colony. Although the photobiology of soft corals is widely studied, most works use moderate (150-200 µmol quanta/m^2/s) to high (up to 1.000 µmol quanta/m^2/s) irradiances levels. This work aimed to study the influence of three different color temperatures (10.000, 14.000 and 20.000 K, with a photosynthetically active radiation (PAR) of 120, 85 and 55 µmol quanta/m^2/s, respectively) provided by 150 W metal halide lamps (HQI), the most commonly employed to supply artificial illumination for corals in captivity, on the photosynthetic performance of *Sarcophyton glaucum* and *Sinularia flexibilis*. The effects of different lights were measured on the photosynthetic activity (through PAM fluorometry), the concentration of photosynthetic pigments (through HPLC) and zooxanthellae density. After the experimental trial, all corals were physiologically healthy, showing a good photosynthetic performance. Nevertheless, a clear photoacclimation response was detected. Corals exposed to a lower PAR presented significantly higher values of maximum quantum yield of PSII (Fv/Fm), zooxanthellae density, and in the content of most photosynthetic pigments. However, no significant differences were found in the concentrations of most photosynthetic pigments per zooxanthellae.

6C Coral physiology & energetics
P071

Corals as solar modulators in ambient sunlight and following coral bleaching

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Corals depend on sunlight for the photosynthesis of their intracellular symbionts and have evolved to be highly efficient at capturing solar energy. Solar radiation intensities underwater vary strongly by orders of magnitude and the lensing effect of waves can produce extremely powerful light flashes. Insufficient light can deprived corals of energy and excessive light can cause the photosynthetic activity of their symbiotic microalgae to lead to heightened oxidative stress and cellular damage. The known mechanisms of light modulation in corals include various morphological, cellular, and molecular adaptations. Here, we used spectroscopic and microscopic analyses of multiple scattered light propagation and fluorescence emissions from the skeletons and the overlying tissues of corals from reefs of the Great Barrier Reef and Lord Howe Island Marine Parks (Australia). We showed that under light limitations, skeletal morphologies act in concert with GFP-type (green fluorescent protein) proteins in coral tissues to increase the available light for photosynthesis. Alternately, in high light, the microstructural skeletal morphologies, together with the overlying fluorescent proteins in tissues, form light modulatory systems optimally tuned for light regulation. Comparison of high and low fluorescent phenotypes of several Lord Howe Island coral species following the most severe mass bleaching event on record at this site in 2010, showed a reduced degree of bleaching of fluorescent corals. Since high light exacerbates the stressful effects of elevated temperature during bleaching, our results supported the photoprotective function GFP-type proteins. Our findings demonstrated a number of new strategies, involving skeletal microstructure and tissue fluorescent protein patterning, that add to the already known photoadaptative mechanisms found in corals that solve the conundrum - too little light causing energy shortness and too much light causing phototoxicity.

6C Coral physiology & energetics
Thursday 12 July, 1015, MR1

Broad scale patterns of metabolism amongst reef building corals

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Light is a major variable regulating the growth and productivity of coral reef ecosystems. Whilst light naturally varies across a continuum of scales (seconds to seasons), this variability will likely be exacerbated via intense anthropogenic activity, e.g. land use change affecting turbidity. Efforts are underway to predict how corals will respond to such change; however, a lack of data describing key metabolic processes regulating biogeochemistry (e.g. gross photosynthesis (P), respiration (R) and calcification (C) rates for corals) still limits confidence of such predictions. Compared to other phototrophs, fundamental broad scale (across environment and taxa) relationships are extremely limited. We therefore initially examined how light regulated P:R:C for both laboratory and field populations of key coral taxa, to examine for broad scale patterns and observed: (1) Alternative underlying photoacclimation 'strategies' (preferentially changing zooxanthellae cell concentration versus pigment per cell) between key coral species, (2) R follows a predictable relationship with P, independent of growth environment or taxa and (3) (light-dependent) C follows predictable relationships with P, independent of growth environment but not taxa. Such novel broad scale trends suggest that metabolic processes (R, C) may be largely predictable from knowledge of P alone. As such, efforts to better resolve variability of coral primary productivity (e.g. through 'convenient' tools such as active fluorometry) could be prioritized in order to better resolve the variability of coral metabolism and its contribution to ecosystem biogeochemical fluxes. We are currently expanding this data set by exploring how additional variables (e.g. temperature) further modify such relationships.

6C Coral physiology & energetics
Thursday 12 July, 1250, MR1

Metabolic performance of *Pocillopora verrucosa* along the S-N gradient in the Red Sea

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The Red Sea is characterized by a large latitudinal gradient with regard to several abiotic variables. Nutrients are introduced from the Gulf of Aden in the South and are gradually depleted towards the North. Salinity increases from 37 in the South (Farasan Islands) to 42 psu in the North (Gulf of Aqaba) and annual mean SST decreases towards the North from 30 to 25°C. These abiotic gradients can be expected to affect the distribution and

performance of reef species. One of the most widely distributed coral species in the Red Sea is *Pocillopora verrucosa* occurring on the Saudi coast along the entire gradient. This makes it a perfect model species to assess coral responses to the interactive effects of nutrients, salinity and / or temperature. Here, the metabolic performance of *P. verrucosa* was investigated at 6 sites from S to N, covering a latitudinal distance of over 11°. In-situ incubations were conducted for photosynthesis, respiration and calcification measurements, and tissue analyses were conducted for zooxanthellae density, photosynthetic pigments, protein concentration, and expression of stress proteins. Results are used to evaluate the metabolic plasticity and acclimatization mechanisms of *P. verrucosa* along the gradient.

6C Coral physiology & energetics
Wednesday 11 July, 1645, MR1

Species-specific dependencies of energy dissipation pathways in two hardcoral species

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The coral symbiosis functions via exchange of fundamental substrates to maintain the symbionts' photosynthesis, and fuel the host metabolism and calcification. Increased temperature and high-light stress can cause oxidative stress, deteriorating active dissolved inorganic carbon (DIC) uptake mechanisms (CCMs), which as a result impact the algal symbionts' photosynthesis and delivery of photosynthetic products to the host. Carbon and oxygen exchange in conjunction with PAM measurements were applied under various light incubations (0 to 1100 µE). Corals were exposed to high-light (500 µE) and thermal stress (31°C) prior to measurements. The inhibitor lincomycin, was applied to simulate gross photoinhibitory conditions as well as the inhibitor DIDS to inhibit CCMs. It was revealed that *Pocillopora damicornis* and *Pavona decussata* relied on differing DIC pools, which influence the capacity for excess energy dissipation of their symbionts. Combined effects of high-light and temperature, deteriorated the CCMs, causing lowered primary productivity. Onset of oxidative stress was more pronounced in the branching species *P. damicornis* compared to the foliaceous species *P. decussata*. The species examined rely on different DIC sources to fuel metabolic pathways of both symbiotic partners. *P. damicornis* relied more heavily on CCMs for DIC, and utilised active energy dissipation pathways. In contrast, *P. decussata* relied on less energetically-costly utilisation for DIC acquisition and energy dissipation. Energetically-costly coral symbioses could be more susceptible towards environmental changes compared to tightly cycled symbioses. This puts species such as *P.damicornis* at greater risk of bleaching under thermal stress events.

6C Coral physiology & energetics
Wednesday 11 July, 1445, MR1

Using metabolomics to investigate implications of diversity in coral-*Symbiodinium* unions

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Increases in anthropogenic stress, such as rising sea surface temperature, are causing mass mortalities on coral reefs that lead to changes in community structure. However, coral species do not respond equally to stressors and some species are more resistant to environmental disturbances than others. Current evidence suggests that coral susceptibility to environmental pressure may be linked to physiological responses associated with endosymbiont identity. While the taxonomic diversity of *Symbiodinium* is well described, the functional differences associated with diversity in coral-*Symbiodinium* assemblages have yet to be fully explored. To this end, we employ metabolomics techniques as a new approach to study metabolite production and translocation within the coral-*Symbiodinium* union. Akin to other 'omics' fields, metabolomics is an unbiased tool in systems biology that describes the metabolic state of a biological system by measuring the presence and abundance of low-molecular weight compounds (<1000 daltons). We investigated the metabolome of two corals from Nanwan Bay, Taiwan, that vary in their endosymbiotic assemblages. Coral fragments were sampled at two time points to capture the photosynthetic and the non-photosynthetic metabolome. Chloroform/ methanol/ water (10:10:7) extracts were made from each sample and were measured using ^{1}H-NMR. Following data acquisition, metabolite profiles were analyzed using multivariate analyses, such as Principle Components Analysis, to display patterns in metabolite assemblages. Our results demonstrate that metabolomics is a viable and powerful tool that can be used to investigate metabolite production in coral-algal unions.

6C Coral physiology & energetics
Thursday 12 July, 1245, MR1

Nutrient assimilation for coral growth and the synergetic effect of elevated seawater temperature

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The effect of nutrient availability and synergetic high seawater temperature on coral growth was investigated in the laboratory condition, considering moderate and realistic nutrient enrichment (2-9 and 0.1-0.6 micromole per liter for nitrate and phosphate, respectively). The growth rate of the adult coral *Acropora digitifera* increased under the nutrient enrichment with the increase in chlorophyll (Chl) of zooxanthellae per unit surface area of the coral. The growth rate of post-settlement juvenile polyps of *A. digitifera* also increased under the nutrient enrichment, but was not correlated with Chl amount of the zooxanthellae for the same nutrient condition. These results suggested that the acquisition of nitrogen was a limiting factor of the coral skeletal growth because nitrogen was necessary for the synthesis of organic matrix in the carbonate skeleton. When the seawater temperature was elevated, the adult corals under nutrient enrichment lost Chl more than those under lower nutrient concentration and the skeletal growth rate dramatically decreased because of the synergetic effect. We speculated that nutrient enrichment increased the photosynthetic activity of zooxanthellae, and resulted in excess oxidative stress on the symbiosis under the high seawater temperature. Moderate nutrient inputs may simply act as an energy source for coral metabolism and a nitrogen source for coral calcification, but considering heat stresses such as global warming, oligotrophic seawater could be favorable for corals to keep a proper degree of the symbiotic algal photosynthesis.

6C Coral physiology & energetics
Thursday 12 July, 1145, MR1

Nutrient transfer from zooxanthellae and host anemone to resident anemonefishes

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Contemporary exploration of symbiotic relationships reveals that these associations can range from 'loosely bound' to 'highly integrated' with regard to nutrient exchange and evolutionary driving forces at the organismal, trophic, and ecosystem level. Associations between anemonefishes and host anemones (and zooxanthellae) are quintessential models of mutualistic symbiosis. Through the use of ^{13}C and ^{15}N stable isotopes, experiments were designed to establish whether nutrient transfer occurs from endosymbiotic zooxanthellae and/or host anemone (*Heteractis crispa*) to resident anemonefishes (*Amphiprion clarkii* and *A. perideraion*) in both laboratory (2007) and field (2010) conditions. One group of anemonefishes was exposed to anemones that had been incubated during daylight in seawater where the natural bicarbonate ion was completely replaced with ^{13}C-bicarbonate ion. Another group of anemonefishes was exposed to anemones that had been fed with ground fresh shrimp mixed with Isogro that was double labeled with both ^{13}C and ^{15}N. Mass spectroscopy analyses demonstrated that ^{15}N and/or ^{13}C were abundant in anemone and zooxanthellae fractions as well as significantly higher levels of ^{15}N and/or ^{13}C in experimental fish tissues (intestines, liver, gills, and reproductive organs) compared to control fish. This was true for both species of anemonefishes and ingestion is the apparent mechanism employed. These experiments provide the first empirical evidence that nutrient transfer of nitrogen and/or carbon products occurs from the zooxanthellae and anemone to anemonefish. Such direct transmission of nutrients from endosymbiotic dinoflagellates and host anemone highlights the fundamental role that nutrient dynamics play in the evolution of this symbiotic paradigm.

6C Coral physiology & energetics
Wednesday 11 July, 1245, MR1

Impact of light microgradients on coral photobiology and energy efficiency

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The physiology of reef-building zooxanthellate corals is fundamentally regulated by their surrounding light environment. Yet surprisingly, little is known about the actual light field that reaches the photosynthetic unit within the coral tissue, specifically when considering the directional and spectral quality of light. For terrestrial plant communities, it is known that differences in leaf morphology strongly affect the degree of light scattering within leaves and thereby regulate the photosynthetic production of chloroplasts. Similarly, the spatial structure of the incident light field, i.e. diffuse vs. collimated, can modulate microscale photosynthetic activity and distribution. Here, we investigate the effect of light collimation on the light microenvironment and photosynthetic response of *Symbiodinium* within coral tissue, using a combination of fiber optic scalar irradiance and O_2 microsensors. Our results show that differences, solely in the spatial orientation of incident light, are sufficient to trigger distinct scalar irradiance maxima in the coral tissue. The degree of light collimation affects spectral composition and light gradients in coral tissue and causes changes in O_2 production within the tissue. We discuss the importance of tissue bio-optics and skeleton microtopography in regulating coral photobiology, and provide new insights into how the microstructure of the light field interacts with coral bio-optics to affect energy efficiency.

6C Coral physiology & energetics
Thursday 12 July, 1035, MR1

Light and oxygen modulate effects of heterotrophy on coralcalcification

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Heterotrophy is known to stimulate calcification by scleractinian corals, which is thought to be mediated through enhanced organic matrix synthesis and photosynthesis, and increased supply of metabolic DIC. The short-term inhibitory effects of heterotrophy on calcification however contrast with long-term experiments, which may be explained by temporal tissue oxygen limitation during feeding. To test this hypothesis, we measured the short-term effects of zooplankton feeding on light and dark calcification rates of the scleractinian coral *Galaxea fascicularis* (*N*= 4)at oxygen saturations of 13 to 280%, using the alkalinity anomaly technique. Significant main and interactive effects ofoxygen saturation, light and feeding on calcification rates were found (three-way factorial repeated measures ANOVA, $P<0.05$). In general, feeding inhibited calcification in darkness but not in light, irrespective of oxygen concentrations. Oxygen promoted light calcification of fed corals at 150% oxygen saturation. In darkness, oxygen was unable to alleviate the inhibitory effect of heterotrophy, as dark calcification rates of fed corals were close to zero at all oxygen saturations. The inhibitory mechanism of heterotrophy may be explained by a reallocation of energy to soft tissue growth and organic matrix synthesis. Alternatively, we hypothesize that heterotrophy impairs calcification by temporarily decreasing the aragonite saturation state of the extracytoplasmic calcifying fluid (ECF) via an increased proton gradient between the calicoblastic ectoderm and the ECF, resulting from increased respiration rates. Our results provide a basis for adding a heterotrophic parameter to the current model of calcification in scleractinian corals. In addition, our results indicate that feeding protocols may require fine-tuning in order to optimise coral aquaculture.

6C Coral physiology & energetics
Wednesday 11 July, 1700, MR1

Variation in biological and functional attributes among perforate and non-perforate corals

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To refine our understanding of the basic biology of corals and the phenomena that underlie their responses to stress, we compared architecture, basic biological traits, and functional attributes in *Montipora aquituberculata, Porites lobata, Pocillopora damicornis* and *Seriatopora hystrix.* The corals examined were maintained at the National Museum of Marine Biology and Aquarium in Taiwan in ambient conditions and explored using light and confocal microscopy, stable isotopes, and the cellular oxidative stress indicator, formazan. Our investigations revealed high levels of structural and biological heterogeneity among coral species and between perforate and non-perforate corals. For example, *Symbiodinium* in the non-perforate branching species (*P. damicornis* and *S. hystrix*) were significantly more enriched with ^{13}C sodium bicarbonate than the perforate massive (*P. lobata*) and plating (*M. capitata*) corals. Additionally, the formazan levels (nmol formazan/ mg protein) among corals varied within and among perforate and non-perforate groups. Oxidative stress indicators did not reflect differences in *Symbiodinium* densities. Rather, baseline levels of oxidative stress in intact coral fragments showed overall patterns of superoxide ion production associated with *Symbiodinium* chlorophyll concentrations. Such emergent patterns exemplify that relationships among coral skeletal architecture and porosity, tissue thickness, and *Symbiodinium* distribution patterns, are contextually important in understanding coral functional responses.

6C Coral physiology & energetics
Thursday 12 July, 1230, MR1

Trophic changes in corals responding to light quantity and quality

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The coral-dinoflagellate symbiosis is highly resilient towards environmental changes. Both host and symbiont are equipped with mechanisms to survive under environmental conditions differing from those regarded as optimal. For example, with decreasing incident light the coral host may support its mainly photoautotrophic diet through heterotrophic feeding while at the same time the symbiont cells contain more chlorophyll leading to an increase in photosynthetic efficiency. While some of these general mechanisms are well accepted, research on other aspects of the acclimation process yielded ambiguous results and requires further attention. In particular, the important deep water coral refuges in mesophotic depths are less well understood and may provide further insight into acclimatization strategies of the coral-dinoflagellate symbiosis. Here, we investigate the influence of different light spectra caused by scattering of phytoplankton on the coral-dinoflagellate symbiosis and nutrients along a cross shelf transect and the influence of decreasing light intensity along a depths gradient in the Central Red Sea. Water optical properties at different sites changed not only in relation to depth, but also due to phytoplankton abundance and pigment concentration. Related cross shelf and depths transects of the symbiont system revealed

acclimatization strategies in photosynthetic performance, densities and pigment concentrations of the symbionts. Additionally, lipid biomarkers revealed a shift in trophic status of the coral host along the environmental gradient. The results give insights into the range of response mechanisms towards varying light regimes over large depth gradients, potentially meaningful in the frame of global environmental change.

6C Coral physiology & energetics
Wednesday 11 July, 1545, MR1

6D Coral physiology under ocean acidification

Impacts of ocean warming and acidification under realistic IPCC scenarios

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Ocean waters are changing rapidly in both temperature and chemistry in response to rising atmospheric CO_2. Understanding the impacts of these changes is extremely important within the context of the sustainable management of coral reefs into the future. Here, we describe a project that has established a state-of-the-art computer controlled system in which sea-water pCO_2 and temperature are manipulated in a flow through system that mimics the natural diurnal and seasonal dynamics of these two variables as they occur at a depth of 5m on Heron Island Reef, GBR, Australia. Conditions simulate preindustrial, present day, and B2 and AIFI IPCC scenarios. Data will be presented from a mesocosm experiment in which replicate mini-reefs are subjected to the different treatments, over many months, and following gradual acclimation. Data will also be produced for experiments on the isolated responses of specific corals to the distinct scenarios in different seasons. The results obtained to date indicate that the carbonate balance of coral reef is significantly threatened by future climate scenarios that are projected to occur by the end of the century. These results are especially important as they simulate combined naturally fluctuating changes in both temperature and ocean acidification, something that has not be effectively achieved in previous studies. The results show elevated coral mortality, reduced calcification, and increased rates of bioerosion for dead coral skeletons exposed to other reefal organisms. The presentation summarizes the efforts of multiple members of the Coral Reef Ecology Laboratory at the University of Queensland.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1115, MR1

Coral nutrient uptake negatively impacted by elevated temperature and pCO_2

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The impacts of ocean acidification and increase in seawater temperature on the calcification and photosynthesis of corals have been extensively investigated over the last two decades. On the contrary, despite the importance of nutrients for coral energetics, the effects of temperature and pCO_2 on the uptake of these nutrients are not known. We therefore investigated the separate and combined impacts of increases in both parameters on the phosphate, ammonium, and nitrate uptake rates of the scleractinian coral *Stylophora pistillata*. Three 10-day experiments were performed in which corals were incubated i) at normal temperature (26°C) under three pH_T conditions (8.1, 7.8, and 7.5), ii) at normal pH_T (8.1) under three temperature conditions (26°C, 29°C, and 33°C), and iii) at elevated temperature (33°C) under three pH_T conditions (8.1, 7.8, and 7.5). No bleaching occurred over the day-day incubation period, and protein, chlorophyll, and zooxanthellae contents were the same in all treatments. Nutrient uptake rates were not affected by a pH_T change alone. Conversely, elevated temperature (33°C) alone increased phosphate uptake rates but led to a release of ammonium and nitrate. The increase of both pCO_2 and temperature lead to a decrease in phosphate and nitrogen uptake rates compared to control corals (26°C, pH_T 8.1). These results indicate that both inorganic phosphorus and nitrogen metabolism may be negatively affected by the cumulative effects of oceanic acidification and warming, even though temperature rise seems to be a far more important factor than pH_T decrease.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1145, MR1

CO_2 and temperature effects on coral photophysiology and symbiont stability

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Four Pacific corals, *Acropora millepora*, *Montipora monasteriata*, *Pocillopora damicornis,* and *Turbinaria reniformis*, were reared in an indoor culture facility and exposed to 3 different levels of pCO_2 representing present day, 40 year, and 100 year future projections (~400, 650, and 800 ppm,

respectively) for 25 days. For each pCO_2 level, a subset of corals was also exposed to gradual thermal heating (from 26 to 30.5°C) over the same time frame. There was no significant difference in the maximum photochemical efficiency (Fv/Fm) of photosystem II (PSII) in any species across CO_2 treatments alone. However, the combined treatment of high CO_2 and increasing temperature resulted in a significant decline in Fv/Fm in *A. millepora* that appeared to be exacerbated as CO_2 increased, while the other corals displayed only marginal declines in Fv/Fm in some CO_2 + high temperature treatments. Likewise, the high CO_2 + elevated temperature treatment resulted in a significant decline in the light acclimated efficiency of PSII (Fq'/Fm') in *A. millepora*, while minimal changes were noted in the other coral species. Respirometry revealed slight declines in the photosynthesis to respiration ratio in some coral species; thus despite the changes noted in PSII photochemistry, overall productivity of each coral species appeared to be largely unaffected by the treatments. These results will be addressed in the context of symbiont type and number, photosynthetic pigments, and calcification of each coral species during this experiment.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1250, MR1

Zinc: a bit of a boost to resist to warming!

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Several patterns on the effects of climate change have already been determined for some coral species but physiological consequences are still relatively speculative. Zinc is among the essential elements for corals, since it is a cofactor of more than 300 enzymes, like carbonic anhydrase. Through the activity of this enzyme, corals continuously acquire inorganic carbon for the photosynthesis of their zooxanthellae and for the calcification of the host. In this study, we have investigated the consequences of ocean acidification and warming on zinc incorporation, photosynthesis, and gross calcification (using ^{45}Ca) in the scleractinian coral *Stylophora pistillata*. Corals were first maintained at normal pH_T (8.1) and at 2 low- pH_T (7.8 and 7.5) for 5 weeks. They were exposed to ^{65}Zn dissolved in seawater to assess uptake rates. After 5 weeks, corals raised at pH_T (8.1) exhibited higher ^{65}Zn activity with a Concentration Factor of 659 ± 93, compared with corals raised at a lower pH (CF = 235 ± 20). Zn was taken less efficiently by corals at reduced pH_T, leading to potential effects on specific coral physiological functions. Photosynthesis, photosynthetic efficiency and gross calcification were however unchanged even at the lowest pH_T, suggesting that zinc deficiency might affect other physiological processes, including nitrogen utilization rates or cellular growth. Colonies of *S. pistillata* were also submitted to 2 temperatures (26 and 30°C) and to normal and higher stable zinc concentrations. The first results obtained suggest that zinc helps corals maintain their photosynthetic capacities under thermal stress.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1530, MR1

Climate and ocean change impacts on coral transcriptome and physiology

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Reef-building corals will experience increasing stress from both increased sea surface temperatures, and declining sea water pH and carbonate concentrations, as atmospheric CO_2 increases. Most studies to date have focused on the destabilisation of coral-dinoflagellate symbioses due to warming oceans, or declining calcification due to ocean acidification. Although these impacts represent major challenges to corals reefs, there is growing evidence that changes to sea temperature and acidity may have other, more insidious, effects on a much wider range of cellular processes. In our study, pH and temperature conditions consistent with the scenarios of the Intergovernmental Panel on Climate Change (IPCC) caused high rates of mortality, and major changes in photosynthesis and respiration, in addition to decreased calcification rates in the coral *Acropora millepora*. Of considerable interest was the observation that symbionts decreased along with both photosynthesis and respiration under high levels of ocean acidification only, yet calcification remained unaffected (possibly a consequence of the precision of the buoyant weight method used). More importantly, observed changes in gene expression of a wide array of processes provide an insight into underlying mechanisms of the complex response at the phenotype level. These changes strongly suggest a much broader cellular response to changes in CO_2, pH, and temperature. Our study reveals the ultility of using next generation sequencing to understand transcriptomic changes

and hence the physiological mechanisms associated with the ability of reef-building corals and their all-important symbiosis with dinoflagellates to survive (or not) projected changes to the Earth's tropical oceans.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1515, MR1

A controllable carbonate chemistry system for novel insights into ocean acidification

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Efforts to understand how ocean acidification (OA) will impact marine ecosystems are resulting in rapid generation of experimentally based manipulations of carbonate chemistry (CC). Differences in approach, notably a lack of closure and/or control of the system CC parameters, have unfortunately led to major difficulties in reconciling observations within and between species. Therefore, as part of an ongoing initiative investigating OA, we developed a new 'stat' system with full control over seawater CC. This system employs a novel Membrane Inlet-Infra Red Gas Analyzer (MI-IRGA) to quantify pCO_2 whilst pH and O_2 are quantified using a standard pH probe and optode. Data is streamed in real time through a customized GUI to control how much CO_2 (or CO_2 free) air is injected into the system to maintain the desired pCO_2 (or pH). Together, these data are used to continuously determine the full carbonate system, although additional independent discrete measures of alkalinity are required to ensure full control of CC. We have grown a number of organisms under pH- and/or pCO_2-stated conditions and yield the first continuous recordings of pCO_2 under changing environmental conditions. Comparisons of reef forming corals and a calcifying alga (*Emiliania huxleyi*) demonstrate that external versus intracellular calcification causes pCO_2 to increase and decrease respectively. As such, quantifying alternative calcification modes across primary producers within shallow water systems will be critical to reconciling changes of net ecosystem drawdown of CO_2. Our 'stat' system opens novel opportunities for more accurately quantifying community responses to OA.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1245, MR1

Flow, oxygen, light and pH: interactive effects on coral growth and metabolism

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Skeletal growth (measured as the increase in buoyant weight over time) and net photosynthesis (Pnet, determined from oxygen evolution measurements in flow chambers) of the stony coral *Galaxea fascicularis* were measured under different combinations of light and water flow, in order to study possible interactions between these factors. In line with comparative studies on other coral species, we found an instantaneous increase in P_{net} upon a sudden increase in flow from 5 to 20 cm s^{-1} when corals were incubated under high light (600 µE m^{-2} s^{-1}). Most likely, this effect is caused by an improved efflux of excess oxygen, thus preventing high rates of photorespiration. Under intermediate light (300 µE m^{-2} s^{-1}), this effect was not significant. In line with these results, light and flow exerted a significant, positively interactive effect on skeletal growth: the highest growth rates were obtained in corals growing under high light and high flow. In our experiments, net photosynthesis was closely coupled to calcification. Other studies have reported an uncoupling of these processes under a decreasing oceanic pH. Therefore, we are currently studying multiple interactions between light, water flow, the concentration of dissolved oxygen, and pH on coral metabolism (photosynthesis, respiration and calcification). Results of this study will be discussed in the light of coral energetics and calcification. We will present a hitherto unknown mechanism by which pH affects scleractinian corals.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1130, MR1

Parental effects may influence acclimatization in corals to climate change

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Larvae from brooding reef corals are critical for replenishing coastal reef ecosystems. Globally, reefs are threatened from the stress of increased temperature and ocean acidification, both of which are predicted to intensify in the future. To understand the acclimatization potential of reef corals, brooding adult *Pocillopora damicornis* were exposed to either ambient or high treatments (26.5℃, 416 µatm, or 29.0℃ 805 µatm pCO_2, respectively) for 1.5 months prior to larval release. Adults were sampled for Fv/Fm, photosynthetic and respiration rates, calcification, *Symbiodinium* density, chl-a, and gene expression. Adult colonies in the high treatment displayed reduced photochemical efficiency and photosynthetic oxygen evolution, and 2.2 times lower P:R ratios than those in ambient conditions. In total, ~55% of the colonies (n=22) released larvae over the course of 4 days, with the majority of release occurring in ambient tanks (58% of 12 colonies, 60% of 858 larvae). Larvae collected over the 3 release days following initial exposure were pooled, allocated to secondary treatment in a reciprocal fashion, and sampled for dark respiration, size, *Symbiodinium* density, and gene expression after 5 days. Dark respiration of

larval *P. damicornis* was significantly affected by the history (initial treatment) of the parent. Together, these results suggest that history and parental effects may play a large role in shaping the physiology of larvae, and subsequent success under future stress. These finding identify the importance of tracking larvae and recruits through time to fully understand these effects at the population level, especially under the continued onslaught of global change.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1215, MR1

Interactive effects of elevated pCO_2 and temperature on coral calcification and energy reserves

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Rising atmospheric CO_2 concentrations threaten coral reefs globally by causing ocean acidification and global warming. Yet, the interactive effects of elevated pCO_2 and temperature on coral physiology and resilience remain poorly understood. In a replicated, controlled experiment, 4 coral species (*Acropora millepora, Montipora monasteriata, Pocillopora damicornis, Turbinaria reniformis*) were reared under a total of 6 treatments for 3 weeks, representing pCO_2 levels for today (400 ppm), the year 2050 (650 ppm), and 2100 (800 ppm), as well as two temperature regimes (26.5 versus 29.0°C) within each pCO_2 level. Preliminary findings show that the response of calcification to both elevated pCO_2 and temperature is highly species-specific, ranging from no effect to carbonate dissolution in some species, and enhanced calcification in another. Interestingly, any treatment effects were only apparent when both pCO_2 and temperature were elevated (800 ppm, 29.0°C), suggesting that pCO_2 and temperature interact only above a given threshold in these species. Overall, these findings suggest that in a future of warming and acidifying oceans some corals could be more resilient than previously expected. Energy reserve data (lipids, protein, carbohydrates) will be presented as well and discussed in the context of calcification.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1545, MR1

Coral metabolic responses to ocean acidification are determined by light availability

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Quantifying the response of corals to ocean acidification (OA) is recognized as a critical step in predicting the future form and function of reef ecosystems. Unfortunately, many (experimentally based) studies still treat OA in isolation of other environmental forcing factors that regulate coral growth and productivity, thus raising concerns as to the relevance of conclusions drawn. Light intensity is an obvious factor that will likely regulate how corals respond to carbonate chemistry changes given the light dependency of photosynthesis and calcification. As such, we grew two coral species (*Acropora horrida* and *Porites cylindrica*) each in a multifactorial design, manipulating both pCO_2 (ca. 380 vs 720 ppm) and light intensity (100 vs 400 µmol photons $m^{-2}s^{-1}$) via state of the art CO_2-stat microcosms: DIC drawdown (light) and release (dark) increased with light and pCO_2; the extent of increase with pCO_2 was the same for both light intensities. Similarly, photosynthesis and respiration (P and R, O_2 evolution) increased with light and pCO_2; however, the extent of increase with pCO_2 was greatest under low light. In contrast, calcification (C, alkalinity drift) increased with light but decreased with pCO_2. Here, the extent of decrease with pCO_2 was greatest under high light (net dissolution still occurred under low light). Thus, increased light exacerbates and dampens the OA - driven changes of C and P(R) respectively, even though DIC changes may appear light independent. Together, these data demonstrate that light availability will determine how OA will alter the functional response of coral dominated ecosystems.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1230, MR1

Heterotrophic feeding in corals may account for resilience to acidification

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Resilience to stress is crucial in a changing environment, and heterotrophy in corals may encourage resilience to climate change. Scleractinian corals contain autotrophic symbionts that provide them with food. Some corals rely solely on their symbionts for food while others supplement that nutrition with heterotrophy. Heterotrophy can meet a small percentage of daily metabolic requirements in healthy corals, but has been shown to meet 100% of metabolic requirements in some bleached corals. Feeding rates of corals appear to be plastic and may vary with environmental changes such as ocean acidification, the decrease in ocean pH resulting from uptake of atmospheric carbon dioxide. As pH declines, the availability of the carbonate ion decreases, retarding calcification. Recent studies indicate that enhanced feeding may mitigate acidification stress by providing extra energy to facilitate the calcium/hydrogen pump required for

calcification. Certain species may be more capable of feeding than others, and such species-specific differences may play a key role in determining resilience. Discovering which corals will be most resilient to acidification will allow prediction of what reefs of the future will look like and corals in other regions with the same heterotrophic abilities. This research will examine the relative contributions of heterotrophic nutrition for coral species in the Florida Reef Tract, how nutritional status affects lipid stores, and whether there is a correlation between feeding rates, lipid stores, and resilience. I hypothesize that corals that can effectively use heterotrophy will exhibit greater energy reserves and demonstrate greater resilience to acidification, as determined by calcification.

6D Coral physiology under ocean acidification
P072

Global coral transcriptomic responses to ocean acidification

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Under global change and anthropogenic pressures, coral reefs are becoming increasingly threatened and show major signs of degradation. Among these disturbances affecting corals, ocean acidification is a major threat that was shown to already affect coral reef health at the present pCO_2. Despite an increasing number of studies, knowledge on the physiological response of corals facing acidification remains fragmentary. In order to fill this gap, we developed a comparative transcriptomic approach on 4 sets of *Pocillopora damicornis* nubbins that were maintained during 3 weeks in different pH conditions (7.2, 7.4, 7.8 and 8.1; this last condition corresponding to the control). The transcriptomes of the 7.4 and 8.1 pH samples were compared using RNAseq (SOLEXA technology) and DEG Seq approaches. The results obtained allow the identification of the physiological functions mainly affected by acidification treatments. In order to strengthen and validate these RNAseq results, we analyze several of the candidate genes identified using quantitative-PCR. This last approach, developed on the 4 conditions tested, allowed verifying by an alternative approach the transcription modulation by the stress. The main result obtained in our study is a general overexpression of genes putatively involved in calcification processes. In addition, we showed a transcription increase of genes involved in energetic metabolisms and a down-regulation of several genes whose corresponding proteins participates to signal transduction.

6D Coral physiology under ocean acidification
Tuesday 10 July, 1200, MR1

Ocean acidification: RNA-Seq analyses after controlled long-term culture of *Stylophora pistillata*

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Ocean acidification in response to rising atmospheric pCO_2 represents major global threats to coral reefs and is generally expected to reduce rates of calcification by reef calcifying organisms, particularly corals. We have performed culture experiments to assess the effects of ongoing ocean acidification on the calcification of coral *Stylophora pistillata* using a high-precision pCO_2 control system. Living clone individuals were subjected to seawater at 4 pCO_2 levels from 400 (pH 8.1) to 5000 ppm (pH 7.2). Cultured individuals were maintained for more than one year in an indoor flow-through system under constant water temperature, light intensity, and photoperiod. After the experiments, RNAs from different clones were extracted and, after reverse transcription, cDNAs were directly sequenced using the Illumina next-generation sequencing platform. The reads obtained from this allowed us to explore transcriptional changes that follow long-term exposure to acidification. Here, we report the changes that occurred in metabolic pathways and correlation with physiological effects. We also compared long-term effects with previously described short-term effect (3 weeks).

6D Coral physiology under ocean acidification
Tuesday 10 July, 1500, MR1

Theme 7. Genomic approaches to coral reef biology

7A Genomic approaches to coral reef biology

The genome of the Red Sea coral *Stylophora pistillata*

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Scleractinian corals are the main builders of the coral reef ecosystem, yet they have been facing steady decline in the past decades. Coral reefs are degrading worldwide due to the accumulating threats of global climate change, pollution and overfishing, which act synergistically increasing coral bleaching and disease. Local populations around the globe rely heavily upon coral reefs for services such as fisheries, tourism, recreation, shoreline protection and construction materials. Therefore reef degradation poses an important economic threat. Although molecular, genetic, and genomic tools such as microarrays and transcriptome sequencing exist, they do not allow us to fully understand the molecular underpinnings of coral health and stress on a genome-wide scale. We are currently sequencing the genome of the coral *Stylophora pistillata* from the Red Sea using short read sequencing on the Illumina HiSeq system. The genome, with an estimated size of 680Mbp and approximately 22,500 genes, will serve as an invaluable resource for ongoing and future projects and will help us to understand how corals build reefs and why some species are able to thrive in harsher environments, such as the Red Sea. Comparative analyses with other coral genomes will shed light on the evolution of scleractinian corals and highlight major biological differences between coral clades. This will allow us to better predict how different coral species are likely to respond to future changes such as global warming, ocean acidification, pollution and the spread of coral diseases and will significantly contribute to current and future conservation efforts.

7A Genomic approaches to coral reef biology
Friday 13 July, 1000, MR1

The molecular basis of settlement and metamorphosis in *Acropora millepora*

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Successful settlement and metamorphosis from a planktonic larva to a settled polyp, which under favorable conditions will establish a future colony, is critical for the survival of corals. Certain aspects of this process are well understood, but important questions remain. I will first summarize our knowledge at a behavioral and morphological level and then relate the changes observed to changes in gene expression revealed by microarray and subtractive hybridization studies. Because the nervous system plays an important role in settlement and metamorphosis, I will focus particularly on the morphological changes that it displays during these processes, as revealed by the expression of the neurotransmitters RFamide and LWamide.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1715, MR1

Location and *Symbiodinium* type drive gene expression during heat stress in *Acropora hyacinthus*

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When large-scale coral bleaching and mortality occur during global warming events, there is often surprising survival of scattered colonies and localized communities, but we know very little about the mechanisms of such tolerance or its underlying genomic causes. Previous research has identified localized elevated stress tolerances in back-reef corals in Ofu, American Samoa, especially from areas with extreme daily temperature fluctuations. We investigated reaction of corals to simulated bleaching using high-throughput gene expression profiles (Illumina sequencing) from *Acropora hyacinthus* colonies. A set of 5 individual *A. hyacinthus* from a highly variable section of the back reef with Clade D *Symbiodinium* and 10 individuals from a moderate area with mixed (C and D) and Clade C were subjected to a 3 day heat stress (~3℃ above ambient). Over 500,000,000 sequences were assembled de novo into ~33,000 contigs with excellent matches to known coral sequences (*Acropora* ESTs and predicted gene models from the *A. digitifera* genome). Our results show that non-stressed corals from different back-reef locations show strikingly different gene expression profiles, indicating that coral location, microclimate and symbiont type may be the driving forces behind basal gene expression patterns. After simulated bleaching, some genes responded equivalently across all corals (primarily heat-shock proteins and molecular chaperones), but some genes showed differential response in corals depending on the original location of the colony.

More work is needed to understand how much of these effects are due to individual acclimation or genetic adaptation at the host and *Symbiodinium* levels.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1745, MR1

Population genomics of threatened Caribbean corals

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Evolutionary adaptation can be rapid, allowing species to survive or thrive during climate change. The challenge is to predict which species have or lack adaptive capacity. The narrow thermal tolerance of corals raises questions about their adaptation potential in response to ocean warming. Changes in the association between coral hosts and symbionts can quickly improve temperature tolerance but such changes might incur fitness costs for the host. The alternative, evolution of de novo host adaptations is thought to be too slow to keep pace with climate change given the long generation times. This assumption underlies models predicting the demise of reefs. However, intra-species, standing genetic diversity can be a source for resistant host genotypes. Here we present the transcriptome of the threatened *Acropora palmata* and use it to build a 135K feature microarray to measure population stress response. Symbiont-free larval cultures (batches), which consisted of gametes from four parents from two populations, were exposed to a range of temperatures. The contribution of each parent to the cultures was monitored over time by genotyping. With time, some parents contributed larger than expected numbers of larvae to the batch cultures while others contributed close to zero larvae indicating selection. Further, parents produced offspring that differed in swimming speed, sperm tail length, lipid content and fertilization rates with some phenotypes showing high heritability. The microarray experiment demonstrated clear gene expression differences among larval batches and populations in response to temperature. Thus, standing genotypic variation might be the basis for survival of this species.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1530, MR1

Genetic and environmental sources of physiological and transcriptomic plasticity

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The persistence of coral dominated reef ecosystems in the face of climate change relies heavily on the ability of hard corals to increase their physiological tolerance through acclimatisation and adaptation. Experiments that reciprocally expose populations to different environmental conditions can reveal the rate of acclimatization and quantify a genetic basis to traits required for adaptive evolution to occur. Here we explore the transcriptomic changes that occurred during a field based reciprocal transplantation experiment in the genomic model coral species *Acropora millepora*. We describe the genetic and environmental sources of variation in growth, physiological condition (total protein, carbohydrate and lipid content, symbiont density) and gene expression among populations separated by 1.5 degrees of latitude. Lastly, we discuss correlations among physiological and gene expression traits to identify the mechanisms that underpin the very large variation observed in coral growth.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1700, MR1

Genetic adaptation across a temperature gradient

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One of the most commonly implicated factors in large-scale coral bleaching events is thermal stress driven by climate change. However, bleaching susceptibility varies both between species and among individuals of the same species. Possible causes of variation in bleaching resistance include genetic adaptation, acclimatization, or a combination of the two in both the host and symbiont. In this study, we used a genomic approach to investigate the contribution of genetic adaptation to bleaching resilience in *Acropora hyacinthus* colonies from backreef pools on Ofu Island in American Samoa. These pools experience different temperature regimes, with one pool regularly exceeding 34°C. Previous studies have shown that individual colonies from these pools vary in their ability to resist bleaching when subjected to thermal stress. The aim of our study was to characterize individual genetic variants that may be associated with increased resilience to thermal stress. Using RNA-seq, we sequenced transcriptomes for 39 *A. hyacinthus* colonies across the natural temperature gradient in the backreef on Ofu. We also collected temperature data from each colony over the span of 6 months. From the full transcriptomes, we identify single nucleotide polymorphisms (SNPs) and test for associations based on location, temperature regime, or symbiont type. Using this information, we can identify which cellular pathways and processes may play a role in thermal tolerance and bleaching resistance in *A. hyacinthus*.

7A Genomic approaches to coral reef biology
Friday 13 July, 1130, MR1

The transcriptome of dinoflagellate symbionts from reef-building corals

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The endosymbiotic relationship between dinoflagellates of the genus *Symbiodinium* and corals forms the basis of coral reefs. As such the biology of *Symbiodinium* is of high interest in coral reef research. However, genetic data is sparse and the genetics of coral symbionts are not well understood, and thus we do not have a clear picture of gene content and expression within this group. We sequenced the transcriptome of *Symbiodinium* strain CCMP2467 of clade A1 at high coverage using next generation sequencing. The transcriptome sequence data was generated by extracting RNA from *Symbiodinium* cultures incubated under different conditions: light cycle, dark cycle, hypo- and hyperosmotic stress, dark stress, heat shock, cold shock, 12h heat stress and 12h cold stress. These reads were assembled to a total of more than 25,000 potential genes of 1000 bp and larger. This data allows for the determination of genes that are differentially expressed between the culturing conditions (RNA-Seq). When compared to the control culture sampled at midday, most of the above conditions result in surprisingly few changes of gene expression. Exceptions were the heat shock treatment, and to a lesser extent the heat stress treatment, for which up- and down regulation of a much higher number of genes were observed. The differentially expressed genes uncovered in this study can provide insight into the genetic basis of physiological traits of *Symbiodinium*, and can thus contribute to the understanding of dinoflagellate genetics in general as well as characteristics of the coral-algal symbiosis in particular.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1750, MR1

Unraveling coral population genetics: A single-tube method to determine SNP allele frequencies

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Recent developments in high-throughput sequencing have led to an explosion of available data, facilitating single nucleotide polymorphism (SNP) detection and analysis. However, applying these methods to population-wide studies, and in particular to non-model systems, has been slow and expensive. Here, we introduce a method for the rapid quantification of allele frequencies in a population and apply it to the reef-building coral *Acropora millepora*. This method expands on the established high resolution melting (HRM) method of genotyping to extract allele frequencies as well as the allele state. We have validated this method by genotyping six adult corals, and found that the allele frequencies as measured by quantitative HRM (qHRM) were correlated with the true frequencies with an R_2 of 0.90. We then applied the method to two natural populations (Orpheus Island and Magnetic Island) represented by 50 and 48 pooled individuals to determine allele frequency differences between them. The results were validated by individual genotyping for 20 SNPs, producing an R_2 value of 0.89. By combining qHRM with the extensive panel of 384 SNPs comprising the *A. millepora* linkage map, this method demonstrates unprecedented high throughput genome scanning in a non-model system, thus advancing the search for loci underlying ecologically important traits in wild populations.

7A Genomic approaches to coral reef biology
Friday 13 July, 1040, MR1

Sequencing the genome of *Symbiodinium* sp. A1 from *Stylophora pistillata*

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Dinoflagellates are ubiquitous marine and freshwater protists. As free-living photosynthetic plankton, they account for ~50% of the primary productivity of oceans and lakes. As photosynthetic symbionts, they provide essential nutrients to corals that are the architects of one of the most productive ecosystems, coral reefs. Here, we report the sequencing of the genome of the dinoflagellate *Symbiodinium* sp. (CCMP 2467), isolated in the Red Sea from the scleractinian coral *Stylophora pistillata*. Using a variety of paired-end and mate-paired Illumina genomic sequencing libraries we have sequenced and then assembled a draft genome of the dinoflagellate. Furthermore, we have also generated and sequenced mRNA-Seq libraries from *Symbiodinium* cultured in a variety of environments conditions. These mRNA-Seq libraries and the genome assembly were analysed using a gene prediction and annotation pipeline to produce a preliminary genome annotation. Functional analysis of the predicted gene products was carried out to identify the variety and frequency of different gene types within the *Symbiodinium* genome. In addition to the *Symbiodinium*, we are sequencing a host species of CCMP 2467, the scleractinian coral *Stylophora pistillata*. Comparing the two genomes will allow the genomic analysis of

the host/symbiont interaction between the two organisms.

7A Genomic approaches to coral reef biology
Friday 13 July, 1200, MR1

Transpacific phylogenomic analysis of *Pocillopora damicornis* populations.

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Pocillopora damicornis is one of the most widely distributed Indo-Pacific reef corals. It is noted for the diversity of habitats that it occupies and its high morphological and reproductive plasticity. Population genetic studies have shown significant genetic structure over kilometer scales and transpacific genetic comparisons indicate that gene flow is restricted across the Pacific, especially between the West and East Pacific. This restricted gene flow may account for the evolutionary novelty in *P. damicornis*, including the reproductive shift from mostly parthenogenetic brooding to free-spawning in the Eastern Pacific. Here we examine the patterns of genome-wide evolution among five Pacific *P. damicornis* populations using restriction-site associated DNA (RAD) sequencing. Our phylogenomic comparisons indicate strong genome-wide differences between Eastern Pacific (Panama) and Central-West Pacific *P. damicornis* populations (French Polynesia and Okinawa) in both coding and non-coding portions of the genome.

7A Genomic approaches to coral reef biology
Friday 13 July, 1035, MR1

The *Acropora millepora* genome

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In the first decade of the 21st century, studies of transcriptomes and genomes of a few cnidarian species have revealed the ancestral complexity of animal genomes. While apparently simple at the cellular level, these animal have a surprisingly rich gene complement. In particular, the building blocks of most animal regulatory pathways seem to have been present in the common ancestor of cnidarian and bilaterian animals. The phylum Cnidaria, however, is ancient and diverse, and the two cnidarian species with a fully sequenced genomes (the sea anemone, *Nematostella vectensis* and the hydra, *Hydra magnipapillata*) barely scratch the surface of this phylum's diversity. The advent of next generation has stimulated a number of other cnidarian genome sequencing projects, including various coral species. The coral *Acropora millepora*, an iconic animal of the great barrier reef, has been chosen as the first large eucaryotic species to be sequenced in Australia. I will give an overview of the Australian coral sequencing project, showing the challenges of sequencing a non-model organism using exclusively ultra short reads from the Illumina next generation sequencing technology. Some of the characteristics of the genome will also be discussed.

7A Genomic approaches to coral reef biology
Friday 13 July, 1445, MR1

Corallimorphs as a model for coral reef stress response

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The corallimorphs 'mushroom corals' belong to a relatively poorly studied clade of anthozoan cnidarians that is closely related to reef-building corals. Regarding the evolution of stress tolerance, a comparison between corallimorphs and hermatypic corals should be very informative, as both groups co-occur in shallow-water tropical habitats, and both rely upon a symbiotic relationship with intracellular algae. In general, corallimorphs are thought to be more stress-tolerant than reef building corals, and they can compete with and overgrow reef-building corals. We subjected 3 species of corallimorph within the genus *Actinodiscus*, that had been acclimated to a salinity of 34 ppt to a brief (3 hr) or extended (27 hr) exposure to either hypersaline (39 ppt) or hyposaline (29 ppt) conditions. RNA was isolated from each species at each test salinity as well as the control salinity (n=3). Non-normalized cDNA libraries were constructed, and deep sequencing was performed on the Illumina platform. The data were assembled into a reference transcriptome, which we then used to test for differential gene expression. The annotated transcripts were deposited into a web-accessible relational database called CorallimorphBase.

7A Genomic approaches to coral reef biology
Friday 13 July, 1250, MR1

Whole genome analyses of the cold-water *Lophelia* coral and related species

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Corals and sea anemones are basal animals with simple tissue level organizations, and represent emerging model systems for environmental stress and gene regulation. We have initiated a genome sequence project (CoralSeq) to study whole genomes and whole transcriptomes of various cold-water species in sub-Arctic Norwegian regions. These include the scleractinian coral *Lophelia pertusa*, the sea anemones *Urticina eques*, *Bolocera tuidae*, *Metridium senile*, and *Hormathia digitata*, and two more distantly related Anthozoans (*Alcyonium digitatum* and *Cerianthus lloydi*). The sequencing approach includes SOLiD ligation sequencing (our in-house facility) for ultra-high throughput of short reads (50 nt), combined with Ion Torrent PGM and 454 pyrosequencing for longer reads (2-700 nt). Our major effort is to complete the genomes at draft-grade resolution that includes gene annotations. The project aims to gain new comparative insight into animal cold adaptation and climate change impact, as well as on basic molecular mechanisms in RNA-based gene regulation.

7A Genomic approaches to coral reef biology
P073

Coral reef management in the post-genomic era

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During 2011, the whole genome sequences of two species representing the dominant reef-building coral genus, *Acropora*, became available, and other coral genomes are likely to be released during 2012. At the time of writing, projects are underway aimed at sequencing the genomes of representative dinoflagellate symbionts of corals, and 16S rDNA profiling is enabling characterisation of the microbial community associated with corals. This mass of data enables deep insights into many aspects of coral biology, but at present there is an enormous gap between the fundamental knowledge acquired and its practical application to coral reef management. Based on molecular data, is it possible to identify genetic loci in the coral and/or its symbiont that are critical to stress resistance, and how can we identify alleles that can confer thermal tolerance? How important is a 'healthy' microflora to corals, and how does this change under stress? What are potential rates of adaptation of corals to climate change? Although these issues may appear to be coral-specific, there are parallels in medical genomics, suggesting the possibility of innovative approaches to coral biology and ultimately management programs based on molecular technologies.

7A Genomic approaches to coral reef biology
Friday 13 July, 1415, MR1

Using next generation sequencing to understand coral reef diversity

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The diversity of small animals on coral reefs is enormous and difficult to study. Molecular approaches hold much promise, particularly given that many species remain undescribed. Earlier studies using standardized sampling combined with barcoding showed that six m^2 of coral reef has nearly as many crab species as all of Europe. Next generation sequencing holds even more promise as it does not require individual subsampling of each organism. Here we show how primers for COI, 12S and 18S, when used together, can recover most of the diversity of communities that settle onto automated reef monitoring structures (ARMS). Global arrays of these standardized samples have the potential to dramatically increase our understanding of reef diversity.

7A Genomic approaches to coral reef biology
Friday 13 July, 1115, MR1

Characterising the transcriptomic response of *Symbiodinium* to stress

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Recent advances in genomics have allowed us to characterise the gene content of both the coral host and their dinoflagellate symbionts (*Symbiodinium*), and allow us to study the gene expression response of the partners when subjected to a stressor. While this data can be used for quantitative PCR studies and examine the response of target genes, our research has indicated that often gene expression level changes in *Symbiodinium* are often not as large as seen in other organisms. We have therefore, for the first time, utilized high throughput Illumina sequencing to characterise the changes in the *Symbiodinium* transcriptome when cultures of clade C1 are subjected to elevated temperatures, elevated CO_2 levels and altered nutrient conditions and linked these transcriptional changes to basic

physiological measures. For each treatment at least 5 million reads were obtained making this one of the largest sequencing effort for *Symbiodinium*. Our results indicate that many of the expression level responses seen in *Symbiodinium* are unlike those that occur in other organisms and have revealed how these dinoflagellates respond to stress at the gene expression level.

7A Genomic approaches to coral reef biology
Friday 13 July, 1400, MR1

Transcriptome and gene-expression studies in the model organism *Aiptasia*

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Aiptasia pallida, a small sea anemone that hosts dinoflagellates similar or identical to those found in reef-building corals, is being developed as a model system for study of the underlying molecular and cell biology of cnidarian-dinoflagellate symbiosis. As a step to that end, we have sequenced and assembled the transcriptome of aposymbiotic (dinoflagellate-free) *Aiptasia* using the Illumina sequencing platform (76-bp and 101-bp paired-end reads). The assembly contains 47,549 contigs with an average length of 706 bp. 69% of the contigs have hits in the non-redundant protein database, but these fall into only 10,369 unique accessions, presumably because the contig set contains both isoforms and non-overlapping fragments of particular transcripts. We will conduct RNA-Seq expression experiments comparing aposymbiotic and symbiotic animals, as well as associated analyses of tissue-specific gene expression by laser-capture microdissection. These studies should allow us to identify the transcripts whose steady-state levels are altered during maintenance of the symbiotic state in the gastroderm and/or epiderm, as well as providing data to complete a transcriptome assembly (already in progress) of symbiotic *Aiptasia*. In addition, we will be using similar methods to elucidate the transcriptional responses to heat and light stress in *Aiptasia*.

7A Genomic approaches to coral reef biology
Friday 13 July, 1145, MR1

Small RNA discovery in *Stylophora pistillata* and *Symbiodinium* sp.

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Although microRNAs (miRNAs) were only characterised ~20 years ago, the growth of our knowledge regarding the biology of this class of small RNAs is nothing short of explosive. With the inclusion of miRNAs, small RNAs are thought to regulate most, if not all, biological processes in an eukaryotic cell. At present, miRNAs have been discovered in over 150 species, which are spread across all kingdoms of life. Very little is known about miRNAs in marine organisms - currently, miRNAs have neither been discovered in corals nor dinoflagellates. The discovery of miRNAs would certainly shed more light on the regulation of genetic expression in both organisms. Here, we present our efforts in extracting and sequencing high quality small RNAs from the coral *Stylophora pistillata* and its algal symbiont *Symbiodinium* sp., which resulted in ~30 million small RNA reads for both organisms. In silico methods were employed to identify miRNAs and other small RNA families contained in the sequencing reads. Potential miRNAs identified in *Symbiodinium* sp. share no similarity to known mature miRNAs, whereas miR-100 and several known sea anemone miRNAs have been found in *S. pistillata*. Novel miRNAs from both organisms will be accessible on miRBase (a miRNA repository, http://www.mirbase.org) upon publication.

7A Genomic approaches to coral reef biology
Friday 13 July, 1245, MR1

Phylogeny of Corallimorpharian (Anthozoa; Cnidaria) based on the mitochondrial genome approaches

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The Corallimorpharia (Cnidaria; Anthozoa), comprising about 45 nominal species, are a small and little studied Order within the Hexacorallia in the class Anthozoa. Corallimorpharia are devoid of skeleton, and are very similar morphologically to both Scleractinia (hard corals) and Actiniaria (sea anemones). Corallimorpharians generally are minor components of a wide range of habitats, which has led to corallimorpharian taxonomy and phylogeny being largely ignored in favor of their more obvious relatives. Ambiguity in systematic relationships between several species of corallimorpharians and actiniarians revealed by recent application of biochemical and molecular techniques to anthozoan phylogeny highlights the urgency of revision of relationships within the Corallimorpharia. In this study, we present complete mitochondrial (mt) genome data covering three families with total 12 species that provide a new insight into the corallimorpharian phylogeny. Twelve complete sequenced corallimorpharian mt genomes have shown three types of gene order. First type contains most genera of corallimorpharians (namely *Actinodiscus*, *Amplexidiscus*, *Rhodactis*, *Discosoma*, *Pseudocorynactis* and *Ricordea*), suggesting this is the common corallimorpharian mt gene order. Second type is a species from *Corynactis*, which lacks photosymbiont. The third type is from a deep-sea corallimorpharian,

Corallimorphus, which gene order is much similar to those of scleractinian. These taxonomic groups may serve as valuable model system for assessing the phylogenetic utility of gene rearrangement synapomorphy. However, evidences such as morphological comparisons and ecological data are required to clarify the relationships of corallimorpharian groups.

7A Genomic approaches to coral reef biology
P074

Gene expression profiles underlying heritable variation in corals' thermal tolerance

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The possibility that reef-building corals might adapt to warming ocean temperatures cannot be evaluated without characterizing natural genetic variation in thermal tolerance, but this remains largely unknown. We addressed this experimentally by crossing colonies of *A. millepora* collected from two different reefs (Orpheus Island, QLD). The set of 30 families produced in this cross displayed a wide range of thermal tolerance during larval stages. Statistical analysis of half-sibling relationships revealed that thermal tolerance was highly heritable in these families (narrow sense heritability = 0.63), demonstrating extensive additive genetic variation in this trait. To identify the functional basis of these differences, we used RNA-Seq to profile constitutive gene expression levels in larvae prior to thermal stress treatments. We found that constitutive differences in gene expression were strongly correlated with subsequent survival, identifying specific gene expression profiles that predict thermal tolerance. qPCR analysis of additional larval families confirmed the predictive power of these expression profiles. Our study has demonstrated for the first time a genetic basis for thermal tolerance in corals, and identified candidate genes potentially responsible for the variation in this trait. These genes suggest mechanistic connections between genetic and phenotypic variation, and identify candidate targets of selection that can now be studied in the context of natural populations and bleaching events.

7A Genomic approaches to coral reef biology
Friday 13 July, 1230, MR1

The early transcriptional immune response of *Acropora millepora*

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Despite the increasing prevalence of diseases and their devastating impact on coral reef ecosystems worldwide, little is known about the immune system of reef-building corals and its role in pathogen recognition, protective host responses and disease pathogenesis. To identify genes involved in pathogen recognition and protective immune responses in corals, the early transcriptional response of adult colonies of *Acropora millepora* to viral and bacterial pathogen-associated molecular patterns (PAMPs) was investigated using mRNA sequencing (Illumina). These experiments revealed that distinct sets of genes are differentially expressed after stimulation with viral or bacterial PAMPs. Amongst the most highly up-regulated genes in response to bacterial PAMPs were coral members of a family of nucleotide-binding proteins that have roles in vertebrate immunity but are absent from the model invertebrates, *Drosophila* and *Caenorhabditis*. The innate immune system of the coral is surprisingly complex and vertebrate-like, and some aspects of vertebrate immunity appear to have very deep evolutionary origins.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1515, MR1

Transcriptomic response of *Acropora millepora* juveniles to ocean acidification

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The impact of ocean acidification (OA) on coral calcification is a subject of intense interest, but is poorly understood in part because of the lack of knowledge on the coral calcification process. Until now, studies of the effect of ocean acidification have mainly focused on physiology, but molecular tools provide a comprehensive and timely approach to both better understand the coral calcification mechanisms and evaluate climate-driven changes in the metabolic properties of corals, including coral calcification. We used the Illumina RNAseq approach to study the effects of acute exposure to elevated CO_2 on gene expression in primary polyps of *Acropora millepora*. This study revealed that OA strongly suppressed metabolism but enhanced extracellular organic matrix synthesis, whereas targeted analyses revealed complex effects on

genes implicated in calcification. In addition, this work led to the discovery of numerous novel candidate genes for a role in calcification, which provide a basis and direction for future studies on coral calcification. This study is the first exhaustive exploration of the transcriptomic response of a scleractinian coral to ocean acidification, and provides an unbiased perspective on its effects on the early stages of calcification. This new approach also demonstrates how transcriptome sequencing of a non-model organism can be employed to gain initial insights into genetic regulation and interaction with the environment as well as to generate novel hypotheses to pave the way for more detailed functional studies.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1630, MR1

Comparative transcriptomics of two marine sponges from the Red Sea

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Marine sponges (phylum Porifera) are one of the deepest branching invertebrates in the tree of life. These ancient metazoans have a fossil record backdating to the Precambrian era. Sponges filter seawater and use microbial particles as food source for their nutrition; furthermore some microbial species can also live in association (symbiotically) within the sponge tissue. Marine sponges are classified into two categories according to the abundance of microbial symbionts found in their mesohyl; high or low microbial abundance sponges (HMA or LMA). In this study, we will present the first genome-wide comparative transcriptome analysis of two marine sponges belonging to the two categories (HMA vs. LMA). We have isolated and sequenced the transcriptomes of the Red Sea sponges *Xestospongia testudinaria* (HMA) and *Stylissa carteri* (LMA) by using a combination of the Illumina HiSeq 2000 and 454 GS-FLX platforms. We conducted comparative analyses in order to identify differences in metabolic and immunological pathways. This correlates with the different microbial abundance and variability of the two sponge species and is also reflected in the metagenome data sets that we produced. This work represents the first and most comprehensive analysis of the active pathways in marine sponges.

7A Genomic approaches to coral reef biology
Friday 13 July, 1430, MR1

Tissue homeostasis and cell lineage differentiation mechanisms in Scleractinian corals.

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Similar to most cnidarians, scleractinian corals exhibit an extensive capacity to regenerate and reproduce clonally. This ability implies that multipotent somatic cell give rise to new 'individuals' during asexual reproduction and/or regenerative processes. Although stem cell systems have been identified in all multicellular organisms, including other cnidarians (i.e. *Hydra*, *Nematostella*), the molecular mechanisms regulating tissue homeostasis in corals are poorly understood. Whilst cellular pluri/multipotency is maintained via specific transcriptional networks and interconnected protein-protein and protein-DNA interactions that regulate chromatin structure, highly conserved signalling pathways regulate cell differentiation. All major signalling pathways known to act in bilaterian stem cell differentiation, as well as a number of stem cell specific transcription factors have been identified in corals. To better understand the extent by which cell differentiation and tissue homeostasis mechanisms in corals resemble those described for other cnidarians and higher metazoans, RNA-seq was performed. We compared transcription profiles between blastula, gastrula, post-gastrula, planula and adult stages from the reef-building corals *Acropora digitifera* and *Acropora tenuis* as well as from cultured cells originating from *A. digitifera* colonies. We will focus on: 1) the expression profiles of stem cell markers such as Piwi, Sox2, Myc, Nanos and Vasa, and their relationships with canonical developmental signalling pathways, to predict gene networks likely to regulate stem cell dynamics at the base of animal evolution and 2) taxon-specific modifications likely to originate coral specific cell types, such as the calcifying epithelium.

7A Genomic approaches to coral reef biology
Friday 13 July, 1255, MR1

Integrative approaches shed light on corals and sponges as emerging model organisms.

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Coral reef organisms such as reef-building corals (phylum Cnidaria) and sponges (phylum Porifera) have attracted a lot of attention due to their biodiversity as well as their close relationships with a multitude of microorganisms that lately has been disturbed by global climate change. Genome-wide analysis of corals and sponges also revealed their evolutionary importance because they diverged very early in the history of metazoan evolution. We present here a new system-level approach to study coral reef biology. Firstly, interaction networks of transcription factors in the reef-building coral,

Acropora millepora, were inferred by integrating planulae transcriptome data, orthology information, and transcription factor interaction networks. We were able to identify a transcription factor repertoire and interaction networks conserved across eumetazoan animals as well as lineage-specific expansion of transcription factor networks. Secondly, the recently published genome of the sponge *Amphimedon queenslandica* was compared with phylogenetically diverse species to identify conserved DNA elements, which are assumed to have transcriptional regulatory roles. Flanked genes around these conserved elements have a diverse spectrum of functions, and are enriched with different functional categories based on the lineages. These DNA elements also showed distinct sequence characteristic compared to the other parts of genome. Taken together, our integrative analysis provides a starting point to understand regulatory networks of corals and sponges and highlights the importance of these species in evolutionary studies.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1740, MR1

Endosymbiosis drives transcriptomic adjustments and genomic adaptations in cnidarians

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To decipher inter-partner signaling within the cnidarian-dinoflagellate endosymbiosis, we developed genomic resources (cDNA library and microarrays) from the symbiotic sea anemone *Anemonia viridis*. Differential gene expression was quantified during thermal stress, with and without UV radiation, between symbiotic vs aposymbiotic specimens and gastroderm vs epidermis. During stress kinetic, each stress showed a specific gene expression profile with very little overlap. The major response to thermal stress is immediate (24 hours) but returns to the baseline levels after 2 days. UVR alone has little effect but potentiates thermal stress, as expression of a second set of genes changed at 5 days. Analysis of genes differentially expressed between symbiotic vs bleached or stressed specimens defined a restricted subset of genes (Kern). Tissue specific expression mapping showed that many genes belonging to this set is specifically enhanced in the symbiotic cells (gastroderm). Altogether, these data define the Kern genes as major molecular components of the symbiotic interaction. Functional annotations highlighted several modified pathways including collagen fibrillogenesis, vesicular trafficking, lipid metabolism, calcium signaling, inorganic carbon transfer and cell death. Phylogenomic investigations of several Kern genes (calumenin, NPC2, SYM32 and dermatopontin) demonstrate that they issued from cnidarian specific duplication events, with one member preferentially expressed in the gastroderm and specifically responding to stress, suggesting both genomic and transcriptomic adaptations to symbiosis. Such host neofunctionalizations would be driven with the physiological constraints of endosymbiosis.

7A Genomic approaches to coral reef biology
Friday 13 July, 1015, MR1

Genomic insights into coral reproductive endocrinology

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Cnidarians exhibit cyclical patterns of gametogenesis and spawning, but it is not clear which genes play roles in establishing and controlling coral reproduction. We hypothesized that aspects of the cellular mechanisms used to establish reproductive cycles might be conserved across metazoans. We used a bioinformatic approach to identify cnidarian homologs of a set of vertebrate hormone receptor, hormone synthesis, and circadian and developmental genes. From a set of 15 initial candidate genes we identified unambiguous orthologs of only a handful of genes, with orthology complicated by gene duplication events through metazoan evolution. For example, it is known that gametogenesis in vertebrates is induced when the glycoprotein hormones luteinizing hormone (LH) and follicle stimulating hormone (FSH) bind to membrane receptors belonging to a family of leucine-rich repeat G-protein coupled receptors (LGR). Bioinformatic analysis suggests that cnidarians possess homologs of these genes, but gene duplication events in animals has obscured orthologous relationships. To understand whether these receptors play roles in controlling gametogenesis in cnidarians, we aimed to reconstruct the phylogenetic history and structure of the LGR gene family across metazoans. In addition to identifying homologs of LGR genes in cnidarians, including a novel LGR from the sea anemone *Aiptasia pallida*, we also identified LGR genes in the early branching metazoans comb jelly (*Mnemiopsis leidyi)* and sponge (*Amphimedon queenslandica)*. We have constructed the most comprehensive LGR phylogeny to date, elucidating gene duplication events and selective pressures on the amino acid sequence. Homology modeling of a predicted cnidarian ortholog of the LH/FSH receptor shows a similar protein fold to the human FSH receptor, suggesting a similar function in ligand binding and possible endocrine role.

7A Genomic approaches to coral reef biology
P075

Genome-wide comparative analysis of *Acropora* corals

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Acropora (Scleractinia, Acroporidae) is one of the most widespread of coral genera coral, having a distribution range from the Red Sea through the Indo-Pacific Ocean to the Caribbean, and has the largest number of extant species. The fossil records show that the genus probably originated approximately 50 million years ago (MYR) and that a major diversification occurred very recently (2 MYR). Therefore acroporids could provide novel insights into the evolution and speciation mechanisms of scleractinian corals. Recently the genomes of two *Acropora* species, *Acropora digitifera* and *Acropora millepora*, were decoded; the genome sizes of both coral are approximately 400 mega base pair and about 23,000 protein-coding genes are predicted in each genome. These data enable deep comparisons to be made between two closely related coral species. To better understand genome evolution within *Acropora*, whole-genome comparisons were performed between the two *Acropora* genomes. Almost all of the *A. digitifera* predicted genes were detected in the *A. millepora* genome assembly, indicating that these two corals possess very similar gene repertoires. Gene components, genome organization, synteny and positive selection between two corals were also investigated. The genome comparison provides some clues about mechanisms underlying the extreme speciation and current success of *Acropora* corals.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1545, MR1

Gene regulation in coral larvae exposed to metamorphic/settlement cues

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Acropora millepora coral larvae show different settlement responses towards bacterial-derived and algal derived cues. Pseudoalteromonas strains J010 and A3, as well as crude extracts of these bacteria, trigger complete larval metamorphosis with low levels of firm attachment to solid substrates. The J010 bacterial cue, tetrabromopyrrole, shortcircuits the normal onset of larval attachment and metamorphosis. In contrast the crustose coralline algae *Porolithon* onkodes and extracts of this alga trigger complete larval metamorphosis and high levels of firm attachment. Expression levels of 47 genes involved in coral immunity and/or settlement and metamorphosis were analyzed in two multiplexed reverse transcription qPCR assays specific for *A. millepora*. Larvae were exposed to the bacterial metamorphic cue for 1, 2, 3 and 12 hours (complete metamorphosis after 6 h), and to the algal settlement cue for 1 hour (complete settlement after 2 h). Expression levels of 20 genes of interest significantly changed after one hour of exposure to one or both of the cues. Four out of the 20 genes changed significantly (in the same direction) after exposure to both cues, while another four genes were regulated in the opposite direction dependent of the cue. The difference in transcriptomic changes of selected genes after exposure to settlement and/or metamorphic cues will assist in deciphering the complex processes involved in early stage coral development. The possible function of those genes in the settlement and metamorphosis processes will be discussed.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1645, MR1

Coral growth anomaly gene expression of galaxin and oncogene homologs

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Growth anomaly (GA) is a coral disease characterized by enlarged skeletal legions. Although negative effects of GA on several of coral's biological functions have been determined, the etiology and molecular pathology of this disease is very poorly understood. We studied the expression of five genes suspected to play a role in pathological development of GA in the endemic Hawaiian coral, *Montipora capitata*, which is particularly susceptible to this disease. Transcript abundance of the five target genes in healthy tissue, GA affected tissue, and unaffected tissue (tissue adjacent to GA) relative to three internal control genes (actin, NADH, and rpS3) were compared using quantitative reverse transcriptase PCR. Galaxin, which codes for a protein suspected to be involved in calcification and thus hypothesized to be up-regulated in GA, was up-regulated in unaffected tissue, but remained constant in GA tissue. The gene expressions of oncogene homologs, murine double minute 2 (MDM2) and tumor necrosis factor (TNF) remained constant in GA tissue, and tyrosine protein kinase (TPK) and beta-gamma-crystallin were down-regulated. These expression patterns were all inconsistent with the patterns in neoplastic diseases of similar macromorphology in humans. These expression data therefore suggest that calcification mechanism is not enhanced in coral GA, and that coral GA is not a neoplasia.

7A Genomic approaches to coral reef biology
P076

Differential metabolisms in *Terpios hoshinota* by comparative transcriptomics approach

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Terpios hoshinota is a blackish encrusting sponge which is able to occupy space on coral reef by killing corals. This sponge has caused the death of more than 30% of hard corals in Green Island, Taiwan. To understand the physiology of this sponge, we used a comparative transcriptomics approach to detect metabolic differentiation among three parts of the sponge - the front part, the distal part and the front part placed in a box for 7 days to restrict contact with corals. Applying the next generation sequencing of Illumina GAII, results shows that the front part performed more metabolisms for biogenesis, but the distal part possessed more activities for apoptosis, catabolism and biogenesis of germ cells, suggesting that the front part of the sponge likely acquired plenty of nutrients from dead coral, whereas the distal part had a greater differentiation activities, e.g., sperm or oocyte cells formations. This evidence also suggests that this sponge is likely to have a sexual life cycle. The sponge placed in a box did not have a high biogenesis activity as the front part did, but activities of catabolism and motility pathways were higher, corresponding to the transformation behavior of the sponge trying to escape from the box. Due to a loss of nutrient supply from corals, the high mobility of the sponge might assist it to find suitable habitats away from stresses (e.g. low nutrient environments). Taken together, the transcriptomic data have provided insights into the sponge and make it possible to explore the molecular ecology of the sponge.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1735, MR1

Genetic acclimation to increasing sea surface temperatures in a coral reef fish

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Climate change is predicted to raise sea surface temperatures by as much as 3°C by the end of the century with detrimental effects on many marine organisms. Thermal acclimation will be critical for population sustainability, though short-term studies have shown that coral reef fishes lack this adaptive capability. In contrast, a recent study showed acclimation of the resting metabolic rate in the reef fish, *Acanthochromis polyacanthus*, when exposed to long-term elevated temperatures. This has led to an important question: how are these fish acclimating? Here we aim to elucidate the genetic mechanisms by which thermal acclimation is possible in reef fish. Preliminary analysis in *A. polyacanthus* of a candidate gene, ldh-b, known to be upregulated in temperature stressed fish, has shown interesting trends of increased expression in the cooler Heron reef population as compared to the more northern Orpheus reef. However, whole suites of genes will be involved in the process of acclimation. We, therefore, have used cutting-edge Next Generation Sequencing to determine transcriptomic changes in expression to pinpoint which genes are involved in thermal acclimation and, potentially, epigenetic inheritance. This research will provide groundbreaking insight into how marine fish will be able to adapt and survive despite the challenges presented by this climate-changing world.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1755, MR1

Coral reef genomics in the Red Sea

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Coral reef ecosystems are among the most diverse ecosystems in the world. They are composed of hard and soft corals, sponges, invertebrates, vertebrates, bacteria, etc. Despite their ecological and economic importance, coral reef cover declines at an unprecedented rate due to global warming, ocean acidification, pollution, and exploitation. Here, we present our current efforts regarding the molecular characterization of coral reef organisms from the Red Sea. The Red Sea is the world's northernmost tropical sea. Coral reefs in the Red Sea exist in an environmental extreme and thrive despite high temperatures and high salinity. The Red Sea forms a perfect natural laboratory to study mechanisms of adaptation to stressors, such as heat, that coral reef organisms have acquired over the past million years. We are currently sequencing transcriptomes, metatranscriptomes, and genomes of corals, algae, sponges, and bacteria from the Red Sea to find genomic clues as to the success of coral reef organisms in the Red Sea. The specific adaptations acquired by Red Sea organisms in regard to their extreme environment can inform us on the underlying genes, pathways, and mechanisms that are subject to adaptation. In the long run, we hope to understand similarities and differences in the molecular assemblage of coral reef ecosystems and how those are subject to change in a changing environment.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1500, MR1

Genomic approaches to understanding holobiont robustness under thermal stress

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The field of symbiosis is growing and encouraging increasingly complex questions about the diversity of partners and cellular level interactions. Basic biology and new methods make functional studies possible. We explored symbiont physiological response and host gene expression patterns resulting from seasonal temperature stress (i.e. winter vs. summer) on a coral holobiont in the Mexican Caribbean. Approximately 170 fragments of a single colony of *Montastraea faveolata* were acclimated under controlled tank conditions before half were used for each seasonal experiment. The treatment fragments were exposed to a 4℃ temperature increase to induce bleaching and subsequently allowed to recover. The same protocol was used for both winter and summer experiments and the physiological parameters (i.e. photosynthetic yield, reflectance, calcification) that we measured showed clear differences between winter vs. summer months. We will discuss tolerance to thermal stress, organismal performance and the host transcriptome responses associated with these physiological differences and we will use this case study to evaluate theoretical models of biological robustness.

7A Genomic approaches to coral reef biology
Friday 13 July, 1215, MR1

Understanding the stress response of reef corals in French Polynesia

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During the last three decades, mass bleaching events and associated mortalities of corals have been reported with increasing frequency, becoming one of the most important threats to coral reefs worldwide. Since the first bleaching record on Moorea by the CRIOBE (CNRS-EPHE USR3278) in 1983, 6 further events were happening within shorter time distances (1987, 1991, 1994, 2002, 2003 and 2007). Bleaching events have been intensively studied worldwide. However the mechanism itself, which takes place during bleaching, remains poorly understood. Most of the work on the impact of elevated temperature and light on *Symbiodinium*-invertebrate symbioses have focused primarily on how the photosynthetic partner is impacted. Understanding how the same stresses affect the host, is however in its infancy. Little is known about the origin of the rejection, the signalling pathway, or the impact of the climate changing. Several studies lead to the hypothesis that bleaching involves the production of reduced oxygen intermediates, or toxic oxygen, in the algae and host tissues that subsequently causes cellular damage and expulsion of symbionts. Despite the well known role of organelles in generation and degradation of ROS, their putative role during bleaching remains unexplored. Since 2009 Veronique Berteaux-Lecellier and coworkers are establishing a holistic approach to elucidate the molecular and physiological coral response to various environmental stresses by using diverse molecular technique, like e.g proteomics, transcriptomics and cytology. This presentation will show preliminary results of a heat shock experiment conducted in the lagoon and will shed light on the role of the organelles during bleaching.

7A Genomic approaches to coral reef biology
Friday 13 July, 1030, MR1

Transcriptomic stignature in soft coral exposed to abiotic stresses

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The cDNA library of the soft coral *Scleronephthya gracillimum* was consturcted and the transcriptional changes of the differentially expressed genes responding to abiotic stresses were investigated. The *S. gracillimum* genes expressions were strongly affected by the exposure to persistent organic pollutants, heavy metals and heat stress. The stress-associated translational changes indicated that an organism activated its cellular defense or biological process against environmental changes. This is the first approach using soft coral and the results suggested that the stress-responsive gene expression could be used as biomarkers for monitoring the health status of the local marine ecosystem.

7A Genomic approaches to coral reef biology
Thursday 12 July, 1730, MR1

Theme 8. Ocean acidification

8A Organism & ecosystem responses to ocean acidification

Resistance to ocean acidification in larvae of a subtropical fish

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Compared to our knowledge of the effects of ocean acidification (OA) on marine invertebrates, our understanding of how acidification impacts larval fishes is rudimentary at best, with only a handful of published studies focused mostly on demersal, benthic-spawning tropical reef species. *Rachycentron canadum* (cobia), a pelagic spawning, subtropical species known to inhabit pelagic, reef, coastal, and estuarine environments, is a useful comparative study species with physiological traits and a life history contrasting those species studied to date. In this study, the effects of OA on larval cobia were investigated during the first three weeks post-hatch, utilizing multiple assays of growth, development, swimming ability, and behavior. Because future OA will not occur in isolation, but rather in combination with increased temperature and potential changes to prey availability and patchiness, trials were also conducted for OA treatments paired with temperature and starvation stress, to identify synergistic interactions. Results indicate that when raised under extreme OA conditions (6,500ppm to 13,000ppm atmospheric CO_2 equivalent), cobia demonstrate reduced size-at-age and delayed development, while under more realistic predicted future scenarios (700ppm and 2,000ppm CO_2), cobia exhibit resistance to impacts on growth, swimming capability, and behavior. Despite this apparently robust nature under predicted future conditions, preliminary analyses also indicate an increased starvation mortality rate and altered otolith development under OA conditions. Further comparative trials with coastal *Trachinotus carolinus* (Florida pompano, Carangidae) and pelagic *Coryphaena hippurrus* (mahi mahi, Coryphaenidae) will contribute to a broad understanding of the effects of OA on marine fishes.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1130, MR5

Monitoring ecological impacts of ocean acidification on Pacific reefs

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Ocean acidification has been predicted to have significant negative impacts on coral reefs and the associated ecosystem goods and services they provide to human societies over this century. To date, efforts to examine the response of marine calcifying organisms and ecosystems to changes in carbonate chemistry have focused primarily on laboratory-based response experiments and simple ecosystem models, respectively, with only limited research and monitoring efforts focused on examining the impacts on coral reefs in nature. To inform, validate, and improve laboratory and modeling studies, NOAA has initiated collaborative efforts to concurrently monitor spatial patterns and long-term temporal trends of seawater carbonate chemistry, benthic community structure and biodiversity, and calcification rates of corals and calcareous algae spanning gradients of biogeography, oceanography, and anthropogenic stressors across the central and western Pacific, and more recently, portions of the Coral Triangle. For each of the reef systems surveyed, surface and near-bottom water samples characterize carbonate chemistry, Rapid Ecological Assessment and towed-diver surveys provide composition and abundance of key benthic functional groups, standardized Autonomous Reef Monitoring Structures provide indices of cryptic invertebrate biodiversity, and Calcification Acidification Units provide net accretion and calcification rates of reef builders. Coral cores collected at a subset of islands surveyed provide growth and calcification rates of key reef-building corals in recent decades. Collectively, these observations of the ecological responses to ocean acidification of reefs in their natural environment are essential to support resource managers and policymakers in their efforts to implement effective strategies to enhance resilience of coral reefs.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1200, MR5

High-latitude coral: assessing the impacts of climate change

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Anthropogenic CO_2 is changing the physical and chemical characteristics of ocean seawater. In the past century average sea-surface temperature has warmed by more than 0.7°C and sea-surface pH has decreased by 0.1 units. Geochemical records preserved within coral carbonate skeletons provide one of the few means to obtain multi-centennial records of paleoclimatic change, through environmental proxies. A widely used proxy for SST is the analysis of oxygen isotope composition ($\delta^{18}O$) preserved in the aragonite skeleton. More recently it has been established that boron isotope composition ($\delta^{11}B$) can be used as a proxy for sea-water pH. When $\delta^{18}O$, $\delta^{11}B$ records are coupled with coral growth and local climate records, they become a reliable source of paleoclimatic information. However, in Australia, coral paleoclimate studies have mainly been focussed at tropical latitudes and on corals of the family Poritidae. Here we extend this knowledge to higher latitudes, where corals experience annual variations of ~7°C and annual fluctuations in pH are still yet to be determined. At high-latitude coral communities are dominated by the family Faviidae, thus we test the reliability of the sub-tropical species *Cyphastrea serailia* as a temperature and pH recorder. In this aim, we analysed $\delta^{18}O$ and $\delta^{11}B$ over the last 55 years in two *C. serailia* cores from Marmion lagoon (32°S, Perth, Western Australia). Confirmation of seasonal and annual variation in isotopic composition was used to quantify changes in sea-water environmental parameters and the significance of Faviidae calcification sensitivity to our changing climate.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1030, MR5

Physiological and reproductive effects of increased pCO_2 on *Echinometra mathaei*

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The pan-Pacific tropical sea urchin *Echinometra mathaei* was maintained for seven weeks four different pH/pCO_2 (pHTotal 7.5-8.0/pCO_2 ~485-1770 uAtm) conditions to investigate the effects of projected near future ocean acidification (OA) on physiology, reproduction and development. There were little to no differences in somatic fitness parameters (growth, respiration) between *E. mathaei* held in pH concentrations between 8.1 and 7.6 for 38 days. Females showed no apparent difference in 'spawnability' after seven weeks in 4 different pCO_2 treatments, and oocytes obtained from those females did not differ in size (average size ~ 36 µm). In contrast, male spawning ability was reduced for animals held at low pH, with the 'spawning-fitness index' reduced by ~50%. To assess the effect of parental acclimation in pH 7.5-8.0 on reproductive success gametes from adults maintained in experimental conditions were used for fertilization in the respective parent acclimation treatment and present day conditions. The performance of these gametes were compared with that of gametes from control urchins maintained at ambient. By the larval stage however, there was a general trend of decreased larval size at low pH as indicated by arm length, regardless of acclimation treatment. Thus, although acclimation at low pH had some positive effects on fertilization and early development, the strong negative effects of reduced pCO_2 even at near future levels on male gamete output and larval development suggest severe effects of OA on *E. mathaei* population size maintenance.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1230, MR5

Nitrogen addition modulates the response of *Hydrolithon* to ocean acidification

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A growing body of evidence suggests that continued acidification of surface waters of the ocean will have significant negative impacts on calcifying organisms and this will be particularly important for taxa that build coral reefs. Calcified crustose coralline algae are important primary producers on coral reefs that bind the reef framework together and often serve as settlement cues for coral larvae. The results of previous experiments indicate that rates of calcification of *Hydrolithon onkodes* are reduced significantly by elevated pCO_2, although the magnitude of the response appears to be habitat-dependent. We conducted an experiment in Moorea, French Polynesia to test the hypothesis that nitrogen availability might modulate calcification responses of *H. onkodes* to elevated pCO_2. Using a crossed-factor design with two levels of pCO_2 (390, 800 µatm) and two levels of ammonium concentration (ambient, 10x ambient), coralline algal samples were incubated for two weeks. Samples exposed to elevated ammonium exhibited significantly higher photosynthetic performance regardless of the pCO_2 treatment. Rates of net calcification were reduced under elevated pCO_2 at ambient ammonium concentrations, but calcification increased significantly with ammonium addition under both pCO_2 levels. The mechanism underlying the effect of ammonium enrichment on the calcification

response is not known, but is consistent with the stimulation of photosynthesis by nutrient addition and a close coupling between rates of photosynthesis and calcification. These results suggest that the effects of ocean acidification on calcification likely will be variable and determined, at least in part, by habitat-related environmental conditions.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1445, MR5

Ocean acidification impacts on seaweeds, algal turfs and coralline algae

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Benthic macroalgae (seaweeds, algal turfs and crustose coralline algae) play critical roles in the ecology of coral reefs. However, little is known about the impacts of increased CO_2 concentrations and associated ocean acidification on physiological, mineralogical and ecological processes of macroalgae. Here, we present results from manipulative pCO_2 and temperature experiments conducted at Heron Island and Lizard Island in the Great Barrier Reef. The experimental algae included a range of fleshy and calcareous red (e.g. *Amphiroa*, *Plocamium*, *Hypnea* and turfs), brown (*Lobophora*, *Sargassum*) and green (*Avrainvillea*, *Halimeda*) seaweeds, mixed algal turfs, and crustose coralline algae (*Porolithon*, *Lithophyllum*, *Lithothamnion* and *Sporolithon*). The group of seaweeds showed variable responses to increased pCO_2 (560-1140ppm), including positive, negative and neutral effects on photosynthesis and growth. Species composition and biomass of algal turfs showed minor responses to ocean acidification. Although calcification of crustose coralline algae was negatively affected by increased levels of CO_2, the magnitude of the response varied considerably across species. We also present data on the mineralogical changes (e.g. mol% $MgCaCO_3$ and type of calcium carbonate) that coralline algae experience under high CO_2 concentrations and elevated temperature. The observed variance in the responses of benthic macroalgae to ocean acidification might be related to variable life history characteristics, the presence of carbon concentrating mechanisms, and in the case of coralline algae, to skeletal mineralogies and evolutionary history. Variability in the responses suggests that the nature of the impacts of ocean acidification on coral reef macroalgae is more complex and diverse than previously considered.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1145, MR5

Coral geochemistry as a tool to reconstruct SST and pH (Clipperton Reef)

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Increased atmospheric CO_2 concentrations from 280 (pre-industrial value) to 390 ppmv (present value) have decreased surface ocean pH globally by approximately 0.1 unit. A further decrease of 0.3 pH units is expected by the end of the century. Geochemical records preserved in the carbonate skeleton of shallow water corals provide one of the few means to reconstruct changes in seawater carbonate chemistry. However, since the early 1990´s, when the potential of $\delta^{11}B$ in biogenic carbonate as proxy for paleo-pH was realised, only few studies report on the recent decadal to centennial pH record. The French island of Clipperton is the easternmost coral atoll in the Pacific Ocean located approximately 1200 km off the coast of Mexico. Due to the small number of ecological niches suitable for coral reefs development, almost no coral-based climatic records exists from the eastern Pacific. The possibility to work on Corals from Clipperton represents a unique opportunity to obtain information on surface seawater properties of this key area. As part of this study we have undertaken, boron and oxygen isotope compositions and elemental ratios (Sr/Ca, Mg/Ca, B/Ca, Li/Mg) have been analysed over the last 80 years of a coral core retrieved in a colony of *Porites australiensis* (located 10°17.506N/109°13.508W, Clipperton island, 10m depth). Boron isotopes were measured by MC-ICPMS, while elemental concentrations were determined using ICP-QMS. Isotopic compositions and elemental concentrations are used to quantify changes in seawater environmental parameters and their significance on the global or more regional Pacific oceanic circulation will be discussed.

8A Organism & ecosystem responses to ocean acidification
P079

Calcification responses to ocean acidification of reef foraminifers

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Ocean acidification is an outcome of anthropogenic carbon dioxide emissions and may severely impact marine calcifying organisms. Although coral responses are known to be generally negative, our knowledge about the responses of reef calcifiers to ocean acidification is quite limited. In a culture experiment with two algal symbiont-bearing, reef-dwelling foraminifers, *Amphisorus kudakajimensis* and *Calcarina gaudichaudii*, in seawater under near-future levels of partial pressure of carbon dioxide conditions, maintained with a precise partial pressure of carbon dioxide-controlling technique, net calcification of *A. kudakajimensis* was decreased under higher partial pressure of carbon dioxide, whereas calcification of *C. gaudichaudii* generally increased with increased partial pressure of carbon dioxide. The opposite responses of these two foraminifer species probably reflect different sensitivities to changes in marine carbonate system, which may be due to their different symbiotic algae.

8A Organism & ecosystem responses to ocean acidification
P080

Coral adaptation to hotter, more acidic oceans

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The release of anthropogenic CO_2 to the environment is leading to climate change and ocean acidification, with potentially severe repercussions for coral reefs. Temperature and pCO_2 vary significantly on reefs over regional and local scales and some corals appear to have adapted to these temperature differences, though it is unclear whether they have adapted to differences in pCO_2. The time scales required for adaptation, where possible, are also unknown. Recent field work has examined coral reef responses to elevated pCO_2 (but not temperature) in upwelling regions or at volcanic CO_2 vent sites. While very informative, these studies have inherent limitations for understanding the combined effects of elevated temperature and pCO_2 on reefs. In contrast, the reefs in the inner portion of Kane'ohe Bay, O'ahu, HI, experience both elevated summertime temperature (1-3 ℃) and elevated pCO_2 (~100 µatm) as compared to regional normal-conditions not expected on most reefs for another 30-80 yrs, depending on CO_2 emissions scenario. Aragonite saturation state on these Kane'ohe Bay reefs is among the lowest measured for any reefs worldwide (Ω arag ~2.8), and is substantially lower than on other nearby reefs (Ωarag ~3.5). In spite of high summertime temperature and low Ωarag coral growth is strong and reef development robust within Kane'ohe Bay, offering a unique opportunity to investigate coral adaptation to global change. We will discuss the evidence that these corals have adapted to high temperature and pCO_2 conditions like those expected for nearby reefs in coming decades.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1430, MR5

A 6-month *in situ* ocean acidification experiment on Heron Island

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Atmospheric CO_2 levels are rising due to anthropogenic activity, resulting in an increase in the CO_2 absorbed by the ocean and a subsequent decline in the ocean's pH. Ocean acidification poses multiple challenges for calcifying marine organisms on all levels from molecular to ecological. These challenges are particularly severe for coral reefs where reduced calcification rates may influence the delicate balance between growth rates and erosional forces. However, previous experimental studies on the impact of future predicted pH levels on coral reefs have mostly been performed in aquarium systems with coral fragments removed from their natural ecosystem and placed under artificial light, sea water, and flow conditions. To avoid these experimental artifacts we deployed the Coral-Proto Free Ocean Carbon Enrichment System (CP-FOCE), the first *in situ* CO_2 enrichment system for coral reefs, and present results from a 6-month deployment on the Heron Island reef flat. Four replicate experimental chambers were used, two that were maintained as controls and two that were gradually reduced to 0.3 pH units below the ambient pH conditions. Five replicate living and recently dead *Porites cylindrica* colonies were placed in each chamber and their calcification rates

monitored along with daily sampling of carbonate chemistry within the chambers and in the environment. Our results reveal that the lowered pH caused reduced growth rates in the living colonies and dissolution of the recently dead colonies. This study reveals that long-term *in situ* manipulative experiments can provide data critical to the management of corals reefs in a changing climate.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1015, MR5

Resilience of coral reefs to an acidifying ocean: the role of pH up-regulation during calcification

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Climate change driven by rising atmospheric CO_2 is not only causing global warming, but also lowering the oceans carbonate saturation state upon which many marine organisms depend to calcify their skeletons. Here we show how the boron isotopic systematics of scleractinian corals reveal that they have a species dependent ability to up-regulate the pH at their site of calcification, such that internal changes in pH are approximately one-half of those in ambient seawater. This extracellular pH buffering capacity enables corals to raise the saturation state of the calcifying medium thereby enhancing calcification. Calcification rates are quantified using a model of internal pH regulation combined with abiotic calcification (IpHrac) which shows that biologic meditation of pH combined with enhanced calcification from rising ocean temperatures has the potential to counter the effects of ocean acidification. Up-regulation of pH at the site of calcification is not however ubiquitous among biogenic calcifiers, being absent for example in many key species of calcitic foraminifera. Ocean acidification is thus likely to cause a major bi-polar shift in the abundance and distribution of marine calcifiers. Those that lack internal pH up-regulation will undergo rapid declines with rising pCO_2 while for tropical corals their resilience to climate change will be largely dependent on their capacity to adapt to increasing thermal stress from rapid global warming.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1000, MR5

Transgenerational effects alter ocean acidification impacts on juvenile reef fish.

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Recent studies have shown that ocean acidification impairs the behaviour and sensory capabilities of juvenile coral reef fish, yet very little is known about how adult fish will respond to ocean acidification. Additionally the potential for parental effects to influence the response of juveniles to high CO_2 (transgenerational acclimation) has not been studied. We investigated the effects of ocean acidification on reproduction in a common coral reef fish, *Amphiprion melanopus*, and tested the potential for transgenerational acclimation to acidification by comparing the performance of juveniles from these parents in different CO_2 treatments. Wild caught breeding pairs were held under 3 CO_2 regimes (control, ~550µatm and ~1050µatm CO_2) for a 9 month period, inclusive of the summer breeding season for 2010/2011. Increased CO_2 had a stimulatory effect on reproduction, with parents in the highest CO_2 producing twice as many clutches, with 30% more eggs per clutch, throughout the breeding season. Juveniles from these parents were then reared under either their parental CO_2 conditions, or were switched to the higher CO_2 conditions. Juveniles from control parents raised at high CO_2 were significantly smaller and had higher resting metabolic rates compared to control juveniles. However, juveniles from high CO_2 parents that were reared under high CO_2 treatments were significantly larger and had significantly lower resting metabolic rates compared to the control offspring reared in high CO_2, and were of a comparable size to the control offspring. This study is the first to demonstrate transgenerational acclimation to rising CO_2 levels in reef fishes.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1040, MR5

Ocean acidification interferes with brain function in marine fish

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One of the most unexpected advancements in ocean acidification research has been the discovery that predicted future CO_2 levels interfere with a range of behaviours and sensory activities of marine fishes. Behavioural changes include increased activity and boldness, loss of lateralization in movement, altered auditory preferences, and impaired olfactory function, the latter making larval fish attracted to smells that they

normally avoid, such as from predators and unfavorable habitats. However, the underlying mechanism responsible for these diverse responses has remained unknown. Here we show that exposure to elevated CO_2 has a systemic effect on behaviour and sensory performance by interfering with brain GABA-A receptor function. Larval reef fish exhibited reversal of olfactory preferences when exposed to high CO_2. This abnormality was rapidly reversed by treatment with a GABA-A receptor antagonist. The results indicate that elevated CO_2 can directly interfere with neurotransmitter function, a previously unrecognized threat to marine species. Given the ubiquity and conserved function of GABA-A receptors we predict that rising CO_2 levels could cause sensory and behavioural impairment in other marine species, especially those that tightly control their acid-base balance through ion regulation.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1115, MR5

Different sensitivity among scleractinian corals to enhanced ocean acidification

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In the past 200 years the oceans have absorbed approximately half of anthropogenic CO_2, leading to a reduction of the pH of surface seawater of 0.1 units and is expected to fall by 0.5 units by the year 2100. The underwater volcanic crater off the Island of Panarea (Tyrrhenian Sea, southern Italy) is a natural CO_2-leaking marine site, with continuous and localized cold emissions (99% CO_2) which create a natural pH gradient, stable through time, making it an excellent field-lab for studying the acidification effects on marine organisms. The effects of increased acidity are being studied along this natural pH gradient on three Mediterranean scleractinians: *Balanophyllia europaea* (solitary, zooxanthellate), *Leptopsammia pruvoti* (solitary, non-zooxanthellate) and *Astroides calycularis* (colonial, non-zooxanthellate). Since July 2010, every 2-3 months, SCUBA surveys assessed the growth rate, dissolution, mortality, reproduction and lesion regeneration, through photographs and sample collection followed by laboratory image, hystological, cytometric, biometric, and biomineralization analysis. Growth rates in the two non-zooxanthellate species are negatively influenced by seawater acidity, while in the zooxanthellate species they do not vary. Preliminary results seem to indicate that enhanced acidity and seawater warming may work synergically, leading to an increased mortality, and in some cases, a decrease in growth rates. These results suggest possible different levels of resilience/resistance to climate change among coral species, probably because of different modes of nutrition and/or biomineralization processes. This natural CO_2-leaking site is expected to provide essential information on the combined effects of ocean acidification and global warming on Mediterranean scleractinian corals.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1415, MR5

Metabolic plasticity in coral larvae under ocean acidification and warming

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The persistence of the coral reef ecosystem as well as the distribution and abundance of corals depend on the successful dispersal and settlement of coral larvae. Metabolic rate was used as an index for assessing the plasticity of *Pocillopora damicornis* larvae to tolerate conditions of ocean acidity and warming during their dispersal. Larvae were incubated for 6 hours in seawater containing combinations of CO_2 concentration (450 and 950 µatm) and temperature (28 and 30°C). An autonomous, modified Honeywell DuraFET® provided a continuous time series of pH on the natal fringing reef throughout the experimental time period. In February/March, 2011, pH values averaged 8.072 ± 0.022, with strict diel oscillations between 10:00 (minima) and 19:30 (maxima). While elevated temperature elicited higher rates of oxygen consumption per larva, there was no effect of CO_2 or its interaction with temperature on aerobic respiration. For larvae released within a day of peak larval release, protein-specific respiration rates did not vary by any fixed factor, indicative of a physiological response at the protein level correlative to temperature. Larvae released later had elevated protein-specific respiration at 30°C, suggesting a decrease in physiological fitness and capacity. Rates of citrate synthase, a rate-limiting enzyme in aerobic metabolism, were also measured. Under short exposures to seawater with twice the acidity of the present fringing reef environment, *P. damicornis* larvae can adjust their current aerobic physiology to balance energy demand and supply, thus enhancing their probability of dispersal and recruitment success. However, this ability varies across the larval release period.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1215, MR5

Controls on calcification rates of coralline algae in Western Australia.

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An increase in atmospheric CO_2 is impacting the worlds oceans by increasing temperature and decreasing pH in surface ocean waters, resulting in ocean acidification. Marine reef-building calcifiers such as crustose coralline algae (CCA) are particularly sensitive to changing seawater properties critical to the production of biogenic carbonates during the process of calcification. Understanding the factors controlling calcification, in particular the interaction between biologic processes mediating calcification together with external changes in seawater properties such as temperature and saturation state, are vital if we are to understand how the structure of reef communities will be impacted in a changing ocean. In the current study, baseline *in situ* calcification rates of representative species of CCA are reported along a latitudinal and temporal gradient in Western Australia. These are compared to variations in chemical and physical seawater properties in order to determine the effects of regional environmental controls on calcification. Biologically induced changes in internal pH and hence saturation state at the site of calcification are being investigated using both solution and laser ablation inductively coupled mass spectrometry (LA-ICPMS) to analyse the pH sensitive boron isotopic composition of carbonate produced by *Porolithon sp.* cultured in the laboratory under ambient and elevated pCO_2 levels. Our findings will establish baseline calcification rates of CCA species in Western Australia and enhance our understanding of both external seawater and internal biologically mediated controls on this process. This will allow us to predict the responses of CCA and the reef systems that they support to future ocean change.

8A Organism & ecosystem responses to ocean acidification
P081

Warmer more acidic oceans reduce productivity and calcification of Halimeda

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Anthropogenic activities have elevated the concentration of carbon dioxide (CO_2) in the atmosphere leading to rising global temperatures and ocean acidification. Consequently, there has been a decline in the abundance of carbonate ions (CO_3^{2-}) and aragonite saturation state resulting in a decreased capacity for calcifiers to produce their $CaCO_3$ skeleton. The sediment producer *Halimeda* (a calcareous alga), is expected to become weaker due to ocean acidification and warming. This study investigated the effects of elevated CO_2 and temperature on photosynthetic efficiency, productivity, calcification and biomechanical properties of *Halimeda macroloba* and *H. cylindracea*. The combination of two temperatures (28 (control), 32℃) and two pCO_2 (380 (control) and 1000 ppm) treatments are equivalent to a range of future climate change scenarios. In both species, photosynthetic efficiency, capacity for non-photochemical quenching and net primary productivity significantly declined in response to elevated CO_2 and temperature, indicating long-term photoinhibition. Biomechanical properties (shear strength and punch strength) of $CaCO_3$ were investigated using a tensiometer. Both biomechanical properties significantly decreased in *H. cylindracea* at elevated temperature (32℃) and pCO_2 (1000 ppm). However, in *H. macroloba*, the effect of pCO_2 and temperature on shear strength and punch strength were variable, indicating different responses between heavily calcified species (*H. cylindracea*) and moderate to lightly calcified species (*H. macroloba*). Measures of $CaCO_3$ density and morphology (using scanning electron microscopy and x-ray diffraction) indicated a significant effect on the structural integrity of these calcifying macroalgae, suggesting these important sediment producers will be one of the losers under climate change.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1035, MR5

***Argonauta* at risk: dissolution and carbonate mineralogy of egg cases**

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Cephalopods are champion mineralisers. Nautilids produce robust external shells and internal mineralised tissues; Spirula makes an internal chambered spiral; sepiids produce flat “cuttlebone”; squids and octopi produce beaks and statoliths. Most cephalopod carbonate is aragonite, but one squid is an exception: the female *Argonauta* secretes a fragile calcitic spiral egg-case. Three argonaut cases were collected at Batemans Bay, NSW, Australia. Four replicate pieces from each were immersed in seawater of varying pH: 8.1 (ambient), 7.8, 7.6, 7.4, 7.1 and 6.7. Weight loss was measured after 7 and 14 days. Dissolution rate increased with decreasing pH, with less than 1% loss in 14 days at pH 7.8, 5% loss at pH 7.4, and 20% loss at pH 6.5. Carbonate from all treatments was analysed using x-ray diffractometry, showing no significant changes in mineralogy as shells dissolved. The pelagic life-habit of cephalopods makes them particularly vulnerable to ocean

acidification. Unlike an internal skeleton, which can be protected from seawater while still needed, the *Argonauta* egg case is exposed to sea water from inception. These egg cases, unprotected by mucous or epithelium, with high surface-area and low volume are particularly vulnerable to dissolution as ocean pH decreases.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1245, MR5

Effect of environmental change on *Porites* growth during the last 100 years

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Experimental and model studies suggest that recent global warming and ocean acidification have dramatically influenced on the calcification processes of marine organisms. Coral cores from massive corals (most commonly *Porites* coral) could provide long-term growth histories in their skeletons with annual bands as well as marine environments during their growth periods up to several hundred years. Large massive *Porites* corals (from 1 to 3 m in height) have been recently recognized at the mid-latitude coastal regions in Japan. We collected the coral cores from two sites at Shimokoshiki island (*P. heronesis*: 31°N 129°E) and Fukue island (*P. heronesis*: 32°N 128°E) in Eastern China Sea side and from two at Tatsukishi (*P. lutea*: 32°N 132°E) and Kushimoto (*P. lutea*: 33°N 135°E) in the Pacific Ocean side of Japan, respectively. Marine environments of these sites in temperate coastal regions are characterized as low temperature, high nutrient, and low aragonite saturation rate relatively to tropical and sub-tropical regions. To address the relationship between coral growth characteristics and environmental changes for coral survival at high latitude area, we reconstructed environmental changes using geochemical proxies ($\delta^{18}O$, SST and SSS, $\delta^{13}C$: sunlight availability and atmospheric CO_2, and $\delta^{15}N$: Nutrients) and physical parameters (skeletal density, extension rate, and calcification rate) using x-ray densitometry. In the presentation, we will discuss the possible linkage of regional and global climate/environmental changes and coral growth in temperate regions and how corals could adapt and survive in marginal and extreme conditions during the last 100 years.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1400, MR5

Calcification, costs, predation: are tropical invertebrates more resilient to OA?

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In addition to corals, heavily calcified marine invertebrates such as molluscs and echinoderms have essential roles in coral reef ecosystems. Ocean acidification caused by anthropogenic CO_2 emissions has been shown to affect shell formation in calcareous marine invertebrates. Baseline data from wild populations of congeneric and confamilial species were collected from the tropics to the poles in order to assess their potential resilience or vulnerability to climate change. Data show tropical species are highly calcified and have high metabolic rates. Calculations on the cost of shell production suggest calcification may be a small proportion of the total energy budget, especially in tropical species. So do these latitudinal gradients infer tropical invertebrate resilience to ocean acidification? Data suggest tropical calcifiers might be some of the more resilient members of these taxa. However, one caveat is predation. Predation pressure is greatest in the tropics and any reduction in calcification may trigger a disproportional increase in predator success rate.

8A Organism & ecosystem responses to ocean acidification
Friday 13 July, 1250, MR5

8B Carbonate chemistry feedbacks within reef habitats

Drivers of seawater carbonate chemistry on Davies Reef, central GBR

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Ocean acidification projections are mainly based on air-sea carbon exchange for open ocean environments, and implications for shallow or near-shore environments such as coral reefs are poorly understood. Coral reefs can naturally experience large fluctuations in seawater carbonate chemistry, driven primarily by biological carbon flux processes: photosynthesis, respiration, calcification and dissolution. Understanding how these processes interact with ocean influences is imperative to

discerning the susceptibility of reef ecosystem to changing ocean chemistry. Here, we present a research initiative that formally analyzes how physical, biological and biogeochemical processes interact in driving carbon chemistry patterns on a shallow-water coral reef system, using Davies Reef (central Great Barrier Reef) as a case study. Using a combination of Lagrangian and Eulerian approaches, spatial patterns of changes in total alkalinity (TA) and dissolved inorganic carbon (DIC) are used to characterize benthic carbon fluxes (net photosynthesis and net calcification) and resulting changes in aragonite saturation state (Ω). The Eulerian approach consists of autonomous water samplers deployed at fixed upstream and downstream positions for a series of reef zones, collecting seawater samples every 2 hours during 48-hour deployments. By encompassing a wide range of benthic community compositions (including corals, macroalgae, turf areas, calcifying algae and sand), flow environments, water depths and light conditions, the data is used to calibrate and test models for how the physical setting and biological environment determine carbonate chemistry feedbacks and the potential for 'biobuffering' of ocean acidification in reef habitats.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1145, MR5

Complex feedbacks between coral reef metabolism and air-sea CO_2 fluxes

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Contemporaneous *in situ* observations of seawater carbonate chemistry and coral reef calcification rates have been episodically collected over the last decade from the high-latitude coral reef ecosystem of Bermuda. These data have allowed examination of the interactions and feedbacks in the natural environment between coral reef metabolism, seawater carbonate chemistry, air-sea CO_2 gas exchange and ocean acidification impacts over diurnal to annual timescales. Moored pCO_2 buoy and sensor data from the Bermuda coral reef, collected as part of the Bermuda ocean acidification and coral reef investigation (BEACON) and earlier studies, show that seawater pCO_2 observed is highly variable seasonally (~330-550 µatm) driven by seasonality in temperature (~8-10°C) and coral calcification rates that induces a strong flux of CO_2 from the ocean to the atmosphere. We examine how the seasonal 'Carbonate Chemistry Coral Reef Ecosystem Feedback' (CREF) between coral reef ecosystem metabolism (i.e., coral calcification and benthic macroalgae photosynthesis/respiration) and seawater carbonate chemistry influences air-sea CO_2 fluxes from the reef system. The CREF process can either suppress or enhance coral calcification seasonally, with complex feedbacks to air-sea CO_2 fluxes.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1230, MR5

pH and pCO_2 sensors to monitor acidification on coral reefs

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Rising atmospheric CO_2 decreases pH and aragonite saturation state of seawater, leading to reduced calcification of some reef calcifiers. Recent models, based on these organismal responses to seawater acidification, indicate reduction of whole reef calcification in the future. There is little evidence, however, of these effects of ocean acidification from measurements of whole reef metabolism. To validate model predictions, it is now essential to improve *in situ* measurements. In an effort to determine responses of whole coral reefs to lowered aragonite saturation state, we are developing methods to monitor *in situ* net calcification. To calculate changes in total alkalinity, dissolved inorganic carbon, and corresponding metabolic parameters; pH, partial pressure of carbon dioxide, oxygen, temperature, salinity, light, and water velocity were measured *in situ* every half hour for several weeks, upstream and downstream, on La Réunion and Kaneohe Bay reefs. This preliminary study is an evaluation of this technique to detect changes in coral reef calcification under different aragonite saturation states, revealing effects of ocean acidification on reef metabolism.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1130, MR5

Permeable carbonate sands modify the carbon chemistry of coral reef waters

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Permeable $CaCO_3$ sediments cover the floor of most coral reefs and support both heterotrophic and autotrophic communities. Generally these sediments are considered fairly biogeochemically inert due to their low carbon content. However, porewater advection in permeable sands efficiently transports reactants deep into the sediment, enhancing the effective area where exchange takes place and magnifying benthic biogeochemical

processes. This presentation will briefly review the drivers of porewater advection in permeable sediments and present a case study from Heron Island that demonstrates the role of permeable sands in proton (H^+), O_2 and CO_2 cycling in a coral reef lagoon water column. The diel ranges in the reef lagoon water chemistry (dissolved oxygen: 28-463 µM; pH: 7.69-8.44; aragonite saturation state: 1.7-6.8) appear to be the broadest, and the night-time values are among the lowest ever reported for healthy coral reefs. Night-time pH (7.69) was comparable to worst-case scenario predictions for seawater pH in 2100. The net contribution of coarse carbonate sands to the whole system H^+ fluxes was only 9% during the day, but approached 100% at night when small scale (i.e., flow and topography-induced pressure gradients) and large scale (i.e., tidal pumping as traced by radon) seawater recirculation processes were synergistic. Reef lagoon sands were a net sink for H^+ and CO_2 and the sink strength was a function of porewater flushing rate. Our observations suggest that the metabolism of advection-dominated carbonate sands may provide a currently unknown feedback to ocean acidification.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1015, MR5

The combined influence of metabolism and hydrodynamics on the carbonate chemistry of coral reef waters

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For more than 65 years geochemist and biologists have derived rates growth and metabolism in coral reef communities from the changes in water chemistry that occurred as a result of this metabolic activity. This started with the seminal work led by Sargent and Austin in the 1940s as well as by the Odums et al. in the 1950s, and then continued by Smith and Kinsey et al. in the 1970s and 1980s and later Gattuso et al. in the 1990s. Recent concern about the potential impact of ocean acidification on the future of calcifying reef organisms has motivated a resurgence of projects aimed at measuring diurnal to inter-seasonal variations in carbonate chemistry in waters surrounding coral reefs in order to better understand how these natural variations will modulate the longer-term effects of rising atmospheric pCO_2 on rates of organism-, community-, and system-scale calcification. Changes in water column carbonate chemistry occur as a result of production, respiration, calcification, and dissolution in the reef benthos; however, they are equally controlled by the hydrodynamic forces driving mixing and circulation at multiple spatial and temporal scales. We will explore how reef hydrodynamics in combination with benthic metabolism influence water column carbonate chemistry through the application of coupled hydrodynamic-biogeochemical numerical models as well as through field observations of carbon metabolism and carbonate chemistry in reef communities across Western Australia.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1115, MR5

Time-series and process investigations at the Atlantic Ocean Acidification Test-bed

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Since 2009, the Atlantic Ocean Acidification Test-bed (AOAT) Project has obtained high-resolution time-series measurements of carbonate mineral saturation state (Ω) and related carbonate chemistry at the La Parguera Marine Reserve in La Parguera, Puerto Rico. This time-series has revealed considerable depression in Ω relative to oceanic values as estimated from the satellite-based Ocean Acidification Product Suite (OAPS v0.6). These near-reef depressions in Ω exhibit seasonality and may reflect the potential for biogeochemical processes to overprint changes in carbonate chemistry due to ocean acidification (OA). In 2011 a series of repeated field studies were conducted in order to improve our understanding of the biogeochemical controls on these seasonal cycles in Ω at the AOAT. Through the application of a boundary layer gradient flux technique, we have quantified net community productivity (NCP) and net ecosystem calcification (NEC) across a seasonal cycle. Together with rates of benthic dissolution and water mass residence time, we evaluated the influence of reef-community metabolism on localized fluctuations in Ω. Understanding the interactions between coral reef communities and their surrounding chemical environment is critical towards improving our understanding of how OA is unfolding within these systems, what local processes dominant control on carbonate dynamics, and how changes in community-scale metabolic performance might alter the influences of OA on reefal waters

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1255, MR5

Community metabolism and Revelle factor cause rapid amplification of coral reef pCO_2

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Increasing pCO_2 from ocean acidification is predicted to affect coral reef species and communities. Perturbation experiments that have exposed organisms or communities to predicted future CO_2 conditions have shown negative effects in many cases. In these studies, the projected changes to seawater CO_2 are derived from measurements that are generally taken in open oceanic waters. However, it has been shown that coral reefs have carbonate chemistry that can vary significantly from the open ocean. In this study we characterise the natural temporal variation in carbonate chemistry of a coral reef flat in the southern Great Barrier Reef and project future chemistry changes under a business-as-usual emissions scenario. We show that local biological processes cause large changes to carbonate chemistry, where natural respiration of organic material presently increases reef flat pCO_2 levels by up to 1000ppm each day. Our projections show that the same biological signal will be amplified 2-fold by the year 2100, with daily pCO_2 levels reaching up to 3320ppm, due to non-linear carbon chemistry associated with the Revelle factor. This amplification process is not an isolated response but is relevant for all coral reefs and productive coastal ecosystems. Our work suggests a critical need to understand the magnitude of biological processes in coral reef environments, since without it we will be potentially underestimating the true extent of CO_2 impacts in the future.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1030, MR5

Linking seasonal changes in benthic community structure to seawater chemistry

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Ocean Acidification (OA) resulting from rising atmospheric CO_2 represents a potentially critical threat to marine calcifiers and the ecosystems they inhabit. Numerous predictions based on *in situ* experiments and computer models suggest that large decreases (up to 50%) in calcification and associated loss of coral reef ecosystems could occur within the next few decades to centuries. The effects of OA combined with physiological stress from rising temperatures, are thought to cause shifts in community structure that accelerate degradation of coral reefs and potentially result in ecosystem collapse. Therefore, OA poses a unique, albeit poorly constrained, challenge to coral reef ecosystems. The Atlantic OA test-bed AOAT in La Parguera, Puerto Rico provides a natural laboratory to autonomously monitor *in situ* seawater chemistry and understand the unique set of feedbacks and interactions between the water column chemistry and the benthic habitats. In 2011, seasonal benthic habitat characterizations were conducted at two reef and one seagrass site to quantify the abundance of major benthic calcifiers and relate changes in benthic community structure to any observed changes in seawater chemistry. Both reef sites were dominated by fleshy macroalgae, and live coral cover ranged from 8 to 10% in all seasons. Preliminary also data indicate subtle increases in calcareous algae and soft coral abundance may coincide with observed seasonal patterns of variability in seawater aragonite saturation state. Further investigation of the relationship between algal abundance and overlying water column chemistry is necessary to fully understand potential feedbacks between the reef ecosystem and reef water chemistry.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1245, MR5

Causes and consequences of variable carbonate chemistry over reef communities

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With the impending threat of ocean acidification, there is an urgent need to understand the biological causes and consequences of variability in carbonate chemistry on coral reefs. Here we coupled high frequency time series data of pH and temperature with growth, calcification rates and benthic community structure on coral reefs across the Northern Line Islands. These reefs experienced large ranges in pH (> 0.2 amplitude) each day, similar to the magnitude of 'acidification' expected over the next century. Reef accretion and coral reef community structure were limited by natural spatial patterns in pH and carbonate chemistry. Net community accretion rates were positively correlated with the magnitude and duration of pH above a location-dependent pH threshold each day. Where daily pH fell below the threshold, fleshy, non-calcifying benthic organisms dominated. Further, we enclosed areas of the reef in benthic chambers to quantify feedbacks between carbonate chemistry

and the benthic boundary layer from community metabolism. Diurnal amplitude in pH was dependent upon the benthic species assemblage and was reliant upon the biomass, productivity, and calcification rate of *Halimeda*. Net primary productivity of fleshy algae (algal turfs and *Lobophora*) predominated on degraded, inhabited islands where net community calcification was negligible, but the chemistry over reefs on 'pristine', uninhabited islands was driven by net calcification of calcareous algae and stony corals. Knowledge about species-specific physiological rates and relative abundances of key taxa whose metabolism significantly alters carbonate chemistry may give insight to the ability for a reef to buffer against or exacerbate ocean acidification.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1000, MR5

Evidence of ocean acidification in seawater around Ishigaki Island

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Carbonate parameters have been collected since 1998 to reveal the progress of ocean acidification in offshore seawater around Ishigaki Island. Although the data gaps exist between 2000-2002 and 2004-2008, the dataset has reached more than a decade. The data have been collected every two months since August 2008 to see the seasonal and inter-annual variations. pCO_2 in seawater showed large seasonal variation with amplitude of more than 100 µatm, which was influenced mainly by seasonal changes in SST. Normalized total alkalinity stayed almost constant, while normalized dissolved inorganic carbon showed increasing trend at a rate of 1.6 µmol kg^{-1} yr^{-1} during 1998-2010 period calculated from a simple linear regression. This value is slightly greater than those obtained from Caribbean (1.2 µmol kg^{-1} yr^{-1}) or from Bermuda (1.3 µmol kg^{-1} yr^{-1}). In order to remove the temperature effects from pCO_2 and pH, these parameters were normalized to a constant temperature, 27.3 ℃, mean annual water temperature at this site. pCO_2 (27.3) and pH(27.3) showed increasing and decreasing trend at rates of +2.6 µatm yr^{-1} and -0.0026 pH, respectively. Increase rate of pCO_2 (27.3) is slightly greater than that for Caribbean (+2.2 µatm yr^{-1}) and for atmospheric record around Ishigaki region (+2.0 µatm yr^{-1}). Although we need to be careful to give the exact rates, considering inter-annual variations caused by climate variability such as ENSO, we can conclude that seawater around Ishigaki Island has been acidified in this decade and should be monitored for a longer time span together with changes in reef productivity.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1250, MR5

Mg-calcite dissolution rate determined by field observation and laboratory experiment

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Future uptake of CO_2 by the oceans is predicted to reduce ocean pH and saturation state (Ωarag). The dissolution of carbonate minerals, Mg-Calcite in particular, has been reported in field observation, laboratory experiment and chamber experiment in field. However, the results have not been compared with each other, because laboratory and chamber experiments in closed system have not replicated the field condition with water flow. In this work, we examined the relationship between Mg-Calcite dissolution rate and Ωarag by both *in situ* field observation and laboratory experiment. Dissolution rate of Mg-Calcite on coral sand community at Ishigaki Island was observed using flow-controlled chamber, and total alkalinity flux across the sediment-water interface was estimated by using the eddy-correlation method. We also measured dissolution rate of Mg-Calcite by controlling pCO_2 level in seawater at laboratory experiment. From field observation, carbonate dissolution was observed when Ωarag was lower than 3.0, and dissolution rate increased with lower value of Ωarag and faster flow condition. A laboratory experiment also confirmed that sediment composed mainly of Mg-Calcite from foraminifera and coralline algae started to dissolve when Ωarag was lower than 3.0-3.2, which is in good agreement with the value observed in the field. With decrease in daytime biotic calcification and increase in night-time abiotic dissolution, coral reefs with moderate coral cover and Mg-Calcite sediments might start to dissolve when seawater Ωarag reaches 2.5. Losses of foraminifera and coralline algae from sediments also indicate that atoll island or reef cements will face difficulty in sustaining their formations.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1215, MR5

Quantifying inter-island variability in aragonite saturation state

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With a growing number of laboratory and field studies reporting potential effects of ocean acidification on coral reef calcification, there is a critical need to better quantify the carbonate system within reef environments. To date, most carbonate chemistry measurements have been conducted in the open ocean, less so in the nearshore ocean and

coral reef ecosystems. Studies involving coral reefs have demonstrated these systems possess highly variable water chemistries that often differ from surrounding oceanic waters. The composition of the benthos and biotic/abiotic processes can greatly affect water column chemistry above the reef. The Coral Reef Ecosystem Division within the NOAA Pacific Island Fisheries Science Center has initiated a field monitoring effort throughout the U.S. affiliated Pacific Islands directed towards quantifying spatial variability of seawater carbonate chemistry, identifying long-term trends, and establishing ecological metrics by which to assess biogeochemical interactions on coral reefs. Discrete water samples were collected at surface and reef-level depths at 24 island ecosystems, enabling a basin-scale spatial assessment of nearshore seawater chemistry from disparate oceanic regimes and benthic coral reef communities. This data, when combined with benthic cover, *in situ* and remotely sensed environmental data, provides a foundation for understanding seawater carbonate chemistry variability across an array of coral reef ecosystems. These findings will help identify the potential effects of ocean acidification on coral reef communities and serve as an important component in developing effective strategies for managing and preserving coral reef ecosystems.

8B Carbonate chemistry feedbacks within reef habitats
Monday 9 July, 1200, MR5

8C Coral calcification & accretion

Seasonal trends in seawater carbonate chemistry and calcification in Bermuda

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Until recently the controls and feedbacks between biological processes and seawater chemistry on coral reefs have been mostly overlooked in the context of ocean acidification (OA). Notably, the process of calcification, which is predicted to be among the most vulnerable processes to OA, releases CO_2 and produces significantly lower seawater pH and saturation state with respect to carbonate minerals on coral reefs compared to open ocean conditions. Hence, if calcification were to decrease in response to OA, this would act as a negative feedback to changes in seawater chemistry induced by oceanic uptake of anthropogenic CO_2. As part of the Bermuda ocean acidification and coral reef investigation (BEACON), a five years monthly time series combined with spatial surveys of seawater carbonate chemistry on the Bermuda coral reef platform as well as measurements of net calcification of corals at the individual and ecosystem scale reveal intricate and non-intuitive controls and feedbacks between seawater carbonate chemistry, biology, and physical processes. As a result of high net ecosystem calcification (NEC) and sea surface temperature (SST), seawater CO_2 maximum (550 ppm) and pH-sws minimum (~7.95) are observed in the summertime on the Bermuda coral reef. In the wintertime, when NEC and SST are low, seawater CO_2 minimum (330 ppm) and pH-sws maximum (~8.15) are observed. In contrast, aragonite saturation state is highest (>3.70) and lowest (<3.0) in the summertime and wintertime, respectively. Interestingly, preliminary results suggest that net calcification of individual coral colonies do not follow the observed trend of net ecosystem calcification.

8C Coral calcification & accretion
Thursday 12 July, 1215, MR5

Sensitivity of coral reef calcification to environmental conditions

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The successful persistence of coral reefs largely depends on the continued ability of corals to rapidly produce strong carbonate skeletons. Controlled laboratory studies demonstrate that coral calcification is sensitive to changes in temperature, light, aragonite saturation state (ΩAr), and nutrient concentrations. Coral reef communities show similar sensitivities, and may be particularly susceptible to the compounded effects of ocean acidification and warming (in addition to the local stresses imposed by coastal development, harmful fishing practices, invasive species, and disease). In order to investigate controls on community calcification under natural conditions, we have quantified the community calcification rate using the alkalinity anomaly method, and compared it to temperature, light, ΩAr and nutrient concentrations. These five variables were measured at a reef in the Red Sea 2-5 times per day for 3 days, during both winter and summer. The calcification rate during study days showed great variability (2-10 mmol/m^2/hr in winter and 2-25 mmol/m^2/hr in summer) and are still being evaluated. The ΩAr is about 4.5, the seasonal temperature range is 25-30℃, and the nitrate concentration is low (~0.2 uM) around my study site. Results of a comparable ongoing study in Puerto Rico, using a Lagrangian approach, will be presented for comparison. The waters in Puerto Rico are less salty (~35psu) than those in the Red Sea (~ 39psu) and have a lower ΩAr (~3.7). Comparing the sensitivities of calcification to the environment at these two sites will provide a better understanding of controls on calcification around the globe.

8C Coral calcification & accretion
Thursday 12 July, 1145, MR5

Effects of ocean acidification on coral calcification: a meta-analysis

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Ocean acidification is widely considered to be a major threat to coral reefs. A large number of experimental studies of its effects on coral calcification have found a range of effects varying from weakly positive to strongly negative. Although this body of work has been summarized in several reviews, a rigorous meta-analysis of the sensitivity of coral calcification to ocean acidification has not been undertaken. Here, using a random effects meta-analysis, we combined the slopes and intercepts of calcification against aragonite saturation states (Ωarag) across 28 independent studies. We then divided the studies into a priori defined groups and statistically tested for differences in the calcification response. The mean sensitivity of calcification to Ωarag was ~15% per unit of Ωarag, with a standard deviation of 1.94 among studies. Surprisingly, factors commonly believed to explain variation in the calcification response, such as duration of exposure, did not explain significant amounts of the variation among studies. In contrast, other factors related to finer details of experimental protocols appear to be important contributors to the responses observed. Our study provides a rigorous foundation for projecting the effects of ocean acidification on calcification in a way that incorporates well-calibrated distribution of calcification responses, but it also highlights the need to better understand the influence of experimental protocols on the calcification response.

8C Coral calcification & accretion
Thursday 12 July, 1245, MR5

Nutrient modulation of the coral calcification response to a natural gradient in ocean acidification

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Much of our understanding of the impact of ocean acidification on coral calcification comes from laboratory experiments rearing corals under a range of seawater pH and aragonite saturation states (ΩAr) equivalent to those projected for the next hundred years. In general, experiments reveal that acidification negatively impacts coral calcification, leading to predictions of mass reef extinctions as rates of calcium carbonate dissolution exceed the rates at which corals and other reef calcifiers can replace it. Natural gradients in ocean acidification across the tropical oceans provide a convenient laboratory within which to test hypotheses about the longer term impact and adaptive potential of corals to acidification of the reef environment. Here we report results of a study in which 3-D CT scan and imaging techniques were used to quantify annual rates of calcification by conspecifics at 12 reef sites representing a range of *in situ* ΩAr from <2.7 to >4.0. No correlation between ΩAr and coral calcification was observed across this range: corals living on low ΩAr reefs appear to be calcifying as fast, sometimes faster than conspecifics living on high ΩAr reefs. We used total lipid and tissue thickness to index the energetic status of colonies collected at our study sites. Our results indicate that energetics plays a key role in the calcification response to ocean acidification. The true impact of acidification on coral reefs will likely be felt as temperatures rise and the ocean becomes more stratified, depleting energetic reserves through bleaching and reduced nutrient delivery to oceanic reefs.

8C Coral calcification & accretion
Thursday 12 July, 1200, MR5

Coral calcification and CO_2: *in situ* and *ex situ* results

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The Bermuda ocean acidification and coral reef investigation (BEACON) aims to further the understanding of the potential effects of ocean acidification to coral calcification and calcium carbonate production on coral reefs. *In situ* (on the reef) and *ex situ* (mesocosm) experiments assessed growth and evaluated net calcification of individual coral colonies of two species common to Bermuda and the Caribbean, *Diploria labyrinthiformis* and *Porites astreoides*. In the *in situ* experiment, 12 corals of each species were transplanted to replicate sites at two locations (n=24 per location): a lagoon patch reef and an outer rim reef, each experiencing small, but significant differences in seawater CO_2 chemistry as well as natural variation in other environmental parameters such as temperature and light levels. Coral growth is measured every 2-3 months using the buoyant weight technique. One year of data show that coral growth rates vary significantly between seasons as well as within and among study locations. Ongoing analysis is expected to reveal what chemical or environmental parameter(s) is most strongly linked to the observed growth rates on the Bermuda platform. In the *ex situ* experiment, calcification of corals grown in ambient seawater are compared to corals grown in treatments manipulated by CO_2 bubbling to reflect future climate change scenarios (ambient, -0.2 pH units, -0.4 pH units). Notably,

initial results suggest that calcification in *D. labyrinthiformis* and *P. astreoides* is unaffected by the CO_2 treatment in the present experimental setup, but additional measurements are needed to unequivocally confirm these results.

8C Coral calcification & accretion
Thursday 12 July, 1250, MR5

Feeding modulates the impact of ocean acidification on coral calcification

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Laboratory experiments and field observations show that ocean acidification negatively impacts coral calcification at both organism and community level. Based on these data, coral reefs are projected to shift from net accreting to net dissolving structures over the next few decades. Nevertheless, emerging evidence suggests that the saturation state at which rates of reef dissolution exceed rates of calcification may differ amongst reef communities. For example, linear extrapolation of community calcification data indicates zero net calcification will be reached in the Gulf of Eilat when Ωar ~3.2 as opposed to Ωar ~ 1.5 in Kaneohe Bay. Verifying these different responses and understanding the processes that generate them is critical for accurate projections of coral reef futures. We investigated the role of nutritional (energetic) status in producing such variability. In CO_2 laboratory manipulation experiments, tropical zooxanthellate corals were either nutritionally enhanced through heterotrophic feeding or reliant on autotrophy alone. Regardless of CO_2 condition, nutritionally enhanced juvenile *Favia fragum*, reared from larvae for 3 weeks under ambient (Ωar =3.7±0.3) or 1600 ppm CO_2 (Ωar=1.6±0.2), accreted more $CaCO_3$ than corals relying on autotrophy alone. Additionally, development was accelerated in fed corals, as measured by the presence of tertiary septa. Although fed corals are not insensitive to ocean acidification, the projected Ωar at which calcification ceases entirely is lower than that for unfed corals. Our results suggest that coral energetic status may play a key role in coral reef response to ocean acidification by delaying the shift from net accretion to net dissolution.

8C Coral calcification & accretion
Thursday 12 July, 1130, MR5

Modelling the effect of ocean acidification on coral calcification.

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Rising atmospheric CO_2 concentrations due to anthropogenic emissions induce changes in the ocean carbonate chemistry and a drop in ocean pH. This acidification process is expected to harm calcifying organisms like coccolithophores, molluscs, echinoderms, and corals. A severe decline in coral abundance is, for example, expected by the end of this century with associated disastrous effects on reef ecosystems. Despite the growing importance of the topic, little progress has been made with respect to modelling the impact of acidification on coral calcification. Here we will present a model for a coral polyp that simulates the carbonate system in four different compartments: the seawater, the polyp tissue, the coelenteron, and the calicoblastic layer. Precipitation of calcium carbonate takes place in the metabolically controlled calicoblastic layer beneath the polyp tissue. The model is adjusted to a state of activity as observed by direct measurements. CO_2 perturbation experiments quantify the impact of a changing seawater carbonate chemistry to the strongly controlled site of coral calcification. The model explains how and why coral calcification is susceptible to changes in seawater pCO_2.

8C Coral calcification & accretion
Thursday 12 July, 1230, MR5

Calcification over space and time in the subtropical Florida Keys, U.S.A.

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Calcification rates of coral and algae respond to environmental variables including temperature, water motion, and ocean chemistry. In shallow-reef environments, these variables are dynamic on diurnal, seasonal, and super-annual time scales. Long-term trends in ocean warming and declining pH (ocean acidification) are confirmed in instrumental records around the globe. The purpose of our work was to examine whether corresponding trends are apparent *in situ* for coral and algal calcification in the context of the high spatial and temporal variability inherent in subtropical reef environments of the Florida Keys. In 2009, four calcification monitoring sites were established adjacent to oceanographic and meteorological monitoring stations along the Florida reef tract from Miami to the Dry Tortugas. Forty colonies of an abundant reef-building coral, *Siderastrea siderea*, were transplanted to fixed apparati that allow buoyant weighing on a semi-annual basis. Algal-recruitment tiles were used to measure net calcification of the encrusting algal community. In 2011, corals were sectioned for analysis of linear extension and Sr/Ca. Coral calcification rate was more than 10 times greater than crustose coralline algal (CCA) calcification. *Siderastrea siderea* calcification was seasonal; calcification rates in summer were almost double those in winter. Site-specific effects were also apparent and could not be explained by temperature, with Dry Tortugas corals

calcifying and extending at the highest rate. The thickness of endolithic algal bands inside the coral skeletons varied with site (Dry Tortugas were the cleanest) and showed an inverse relation to extension rate, indicating water-quality variables could be covariates with coral growth.

8C Coral calcification & accretion
Thursday 12 July, 1115, MR5

The growth rate of *Porites* corals from Malaysian waters

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Skeletal growth parameters such as annual skeletal extension rate, calcification rate and density banding were measured in 6 samples of massive reef-building coral, *Porites*. Coral samples were collected at 3m and 5m depth in Pulau Besar and Pulau Aur in the South China Sea, and in Pulau Songsong, in the Straits of Malacca. *In situ* measurements of environmental parameters showed a variation between the South China Sea and the Straits of Malacca with lower pH in the Straits of Malacca. X-radiograph and UV-light techniques were used to measure the growth parameters. This study indicates that there are differences in the formation of the high density (HD) and low density (LD) of the annual growth band between the samples from the South China Sea and the Straits of Malacca. Illumination of the coral slabs by UV-light revealed a distinct fluorescent banding pattern on coral samples which usually associated with the wet season period. Using the available environmental data, it shows that sea surface temperature and salinity between these two reef zones had influenced the growth of *Porites*. An interesting growth band was noticed in the coral samples from the South China Sea between the year 2008 and 2009 which believed to be associated with the El Nino phenomenon. The results from this study will provide a better understanding on the effects of climate change on the corals in Malaysian waters. The effect of ocean acidification with global warming could be even more devastating to coral ecosystems.

8C Coral calcification & accretion
Thursday 12 July, 1240, MR5

A spatial-temporal analysis of coral calcification rates in Bermuda

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In light of ongoing pressures from ocean acidification (OA) there is a need to understand the response of corals both at the community and individual colony level and at intra annual and diurnal timescales. Natural growth-rate fluctuations across diurnal and seasonal timescales have direct feedbacks on the surrounding water chemistry which are analogous to changes driven by elevated CO_2. A temporal assessment encompassing both seasonal and diurnal analyses may therefore identify threshold environmental conditions that only support net positive calcification during the summer or daytime. These data can be applied to predict a critical tipping point between net positive calcification and dissolution for corals living in a future higher CO_2 world. Seasonal net community calcification rates were measured at 4 sites across the Bermuda reef platform by application of a novel radiochemical approach to the alkalinity anomaly method which revealed the greatest seasonal variability at the platform edge with net community calcification rates ranging from 90 (± 20) mmol $CaCO_3$ m^{-2} d^{-1} in November 2008 to -7.0 (0.7) mmol $CaCO_3$ m^{-2} d^{-1} in February 2009. Calcification rates of individual coral colonies were also measured through the application of a calcein dye staining method and showed similar temporal and spatial variations. Diurnal calcification rates were achieved by *in situ* incubations of coral nubbins which indicates net positive calcification during the day and depressed rates or net dissolution at night.

8C Coral calcification & accretion
Thursday 12 July, 1235, MR5

8D Effects of ocean acidification

Red macroalgae, potential losers under doomsday conditions despite eutrophication

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Coral reefs are threatened by climate change and ocean acidification. Benthic algae, very important primary producers of this ecosystem, are expected to thrive under increased pCO_2 and temperature as well as increased nutrient load. Red algae in particular are expected to dominate future coral reefs due to their physiology. In this study, *Hypnea pannosa*, a red seaweed common to Heron Island reef (Great Barrier Reef, Australia), was subjected to two different IPCC climate change scenarios (A1FI and B1), as well as to pre-industrial and present day temperature and CO_2 conditions. Also, nutrients were added continuously to half of the treatment tanks, 3 µM ammonia and 1 µM phosphate, in order to simulate eutrophication. Several physiological parameters, such as productivity, photosynthetic efficiency, biomass and C:N:P ratios, were measured after the experimental period of five weeks. Interestingly, the biomass of the specimen grown under A1FI scenario conditions increased significantly less than that of the algae in

all other treatments, irrespective of the nutrient concentration. These results contradict widely held views of the scientific community and more research should be done to further investigate these findings.

8D Effects of ocean acidification
Thursday 12 July, 1015, MR5

Ocean acidification influence on the growth of *Porites panamensis* in the Gulf of California, México

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Sea surface waters are becoming more acidic due to the increased oceanic uptake of atmospheric CO_2.This results in a decrease of the sea water carbonate ion concentration and therefore the aragonite saturation level (Ωar) drops. Concerns about this phenomenon and its consequences have led to suggest the Eastern Tropical Pacific as a model to visualize coral reef development in a world with high levels of CO_2 because its surface waters have lower pH, lower Ωar and higher pCO_2 values than other tropical waters. To assess the ocean acidification influence on coral growth parameters, we selected three regions of the Gulf of California with contrasting Ωar. This values change in a latitudinal gradient: northern gulf (29°N, 113°W) ≈2.83, middle gulf (26°N, 111°W) Ωar ≈2.92, and southern gulf (24°N, 110°W) Ωar ≈2.98. As model we used *Porites panamensis*, a common coral in the gulf. Skeletal extension was measured from X-radiographs as the width of annual density bands (3 replicates per colony; 10 colonies per site); density using photodensitometry of X-radiographs; and calcification rate calculated by multiplying the density value of each annual band by its corresponding skeletal extension. All growth parameters decreased with decreasing Ωar, skeletal extension and calcification rates were three times lower in the north (0.58 vs 1.53 cm yr^{-1}; 0.53 vs 1.86 g cm^{-2} yr^{-1}), while density rate were more alike (0.92-1.22 g cm^3). The age of the colonies were higher in the northern (≈30 yr) than in the middle (≈5 yr) and the southern gulf (≈16 yr).

8D Effects of ocean acidification
Thursday 12 July, 0945, MR5

Ocean warming and acidification on early life history of corals

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The 'double trouble' scenario of elevated ocean temperature and acidity is becoming of increasing interest in the field of climate change research. Interestingly, events early in the life history of corals, prior to the initiation of calcification, such as fertilization, embryogenesis, larval survival and settlement are not overly affected by high acidity. Indeed, effects on these early life stages are usually only apparent when using unhealthy individuals or at unrealistically high levels of acidity. However, possible synergistic effects of temperature and acidity have yet to be widely explored. Here, we tested the effect of ocean acidification in combination with elevated temperature on fertilization, development, survivorship and metamorphosis of two spawning acroporids from the Great Barrier Reef. We used four treatments: control, elevated temperature (+2°C), elevated acidity (600 - 700 ppm) and a combination of elevated temperature and acidity. These values correspond to the current values and the predicted values of atmospheric pCO_2 within this century. We found no consistent effects of acid on fertilization, development, survivorship, metamorphosis and post-settlement growth rates, either alone, or acting synergistically with temperature. In contrast, temperature consistently increased rates of development, but otherwise had little effect. We conclude that ocean acidification is not a threat to the early life history stages of Great Barrier Reef

8D Effects of ocean acidification
Wednesday 11 July, 1645, MR5

Relationship between pCO_2 and the physiology of 8 reef species

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Despite a general concern regarding the effects of ocean acidification (OA) on tropical reefs, few empirical studies to date quantitatively parameterize a comprehensive relationship between the physiology of reef organisms and pCO_2. Our study aims to fill this gap by investigating the effect of a gradient of six pCO_2 levels, ranging from 280 ppm to 2300 ppm, on the physiology of 4 scleractinian corals (*Acropora pulchra*, *Porites rus*, *Pocillopora damicornis* and *Pavona cactus*), and 4 calcified algae (*Hydrolithon onkodes, Lithophyllum flavescens, Halimeda macroloba* and *Halimeda minima*). After 2 weeks of acclimation, sample organisms were incubated in 150 L aquaria for 2 weeks at the targeted pCO_2 levels and calcification and respiration were measured. The buoyant weight technique was used to measure the net response of calcification over the incubation period and the total alkalinity anomaly method was employed to differentiate the variations in light and dark calcification. Respiration rates were not significantly

affected by variation in pCO_2 treatment. Calcification rates decreased as a function of increasing pCO_2 in both corals and crustose coralline algae. However, both taxa were still able to calcify in the very highest pCO_2 treatments, where the calcium carbonate saturation states were ~ 1. In general, dark calcification decreased as a function of increasing pCO_2, whereas the light calcification response was more species-specific. Our results suggest that the response of tropical reefs to OA will be highly species-specific and that OA might lead to changes in patterns of diversity in a high CO_2-world.

8D Effects of ocean acidification
Wednesday 11 July, 1500, MR5

Ocean acidification increases juvenile coral mortality from herbivorous fish grazing

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Herbivory benefits coral recruitment by increasing optimal settlement space and limiting post settlement competition through the removal of fleshy algae. Yet, evidence has also demonstrated that new recruits are vulnerable to grazer induced mortality before their size reaches 6 polyps. Importantly, recent experiments have demonstrated that recruit growth is reduced by ocean acidification (OA). Thus, we hypothesized that coral mortality would increase when recruits interact with herbivorous fish, due to the reduced coral growth from OA. We cultured newly settled corals (*Acropora millepora*) with three OA treatments, representing ambient (389 µatm), mid (753 µatm), and high (1267 µatm) pCO_2. After 2 months, the size of the recruits decreased as pCO_2 increased. We then ran grazing trials on the settlement tiles with the coral recruits using three herbivorous fish; a blenny (*Salarias fasciatus*), surgeonfish (*Acanthurus nigrofuscus*), and parrotfish (*Scarus rivulatus*). We found independent effects of CO_2 treatment and spat diameter on recruit survival, in that corals grown at elevated pCO_2 and smaller recruits both suffered higher mortality. This pattern was consistent among fish groups, but the magnitude of the effect was significantly highest with parrotfish grazing, which increased coral mortality by 35% at mid and 53% at high pCO_2 compared to ambient. Early growth is important to the survival of many recruiting benthic invertebrates, and if the patterns demonstrated in our study occur with other marine calcifiers, the potential for coral reef recovery following disturbances could be reduced by future levels of OA.

8D Effects of ocean acidification
Wednesday 11 July, 1430, MR5

Tropical CO_2 seeps: ecological adaptations and processes at elevated CO_2

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Three CO_2 seeps in eastern Papua New Guinea were used to assess the effects of long-term exposure to elevated CO_2 on natural coral reef and seagrass communities. Bubble streams of almost pure CO_2 have exposed these reefs to elevated CO_2 for at least 70 years. Reefs persist in the zone where pH is reduced from 8.1 (ambient) to 7.8 units (seawater temperatures are not altered measurably in this zone). However these reefs show substantially reduced diversity, structural complexity and coral juvenile densities. We highlight some of the ecological results from work at these sites, quantify changes along the three gradients in seawater carbonate chemistry, and contrast ecological functions of coral reefs exposed to high CO_2 with those of control sites. We also contrast direct effects of elevated CO_2 on biota with indirect effects, derived from loss in structural complexity. Finally, we present some data on the combined effects of high CO_2 and heat stress on corals. This study suggests that ocean acidification alone will lead to profound changes in the ecology of coral reefs throughout this century, and that the effects of ocean acidification on coral reefs will be exacerbated by increasing seawater temperatures.

8D Effects of ocean acidification
Wednesday 11 July, 1630, MR5

Development of Ocean Acidification Flow-Thru Experimental Raceway Units (OAFTERU)

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Critical needs have been to use projected pCO_2 (partial pressure of CO_2 in seawater) levels in manipulative experiments to determine physiological indices of ecologically important species, such as corals. The Florida Keys reef system has already experienced a long-term deterioration, therefore, reef resilience to ocean acidification and the potential for successful restoration of these systems under forecasted long-term modified pH conditions is of great concern.

Many studies for testing effects of ocean acidification on corals have already been established and tested. However, many employ pH modification experimental designs that include addition of acid to seawater which may not mimic conditions of climate change induced ocean acidification. The Mote Marine Laboratory research facility in Summerland Key, FL has an established deep well from which its supply of seawater is obtained. This unique source of seawater is 80 feet deep, "fossil" marine water. It is pumped from the on-site aquifer aerated to reduce H_2S and ammonia, and passed through filters for bio-filtration, and clarification. The resulting water has a pH that is relatively acidic (pH around 7.6, pCO_2 ranging from 200 to 2000 µatm). However, further aeration will adjust the pH of the water, by driving off more CO_2, yielding pH levels at varying levels between 7.6 and present day values (>8.0-8.4). We are currently testing and will report methods for utilizing this unique seawater system as the foundation for multivariate manipulative ocean acidification studies with Florida Keys corals and other reef ecosystem species in both flow-through and large mesocosm-based designs.

8D Effects of ocean acidification
Thursday 12 July, 1000, MR5

Carbonate chemistry influences recruitment and physiology of tropical calcified algae

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The consequences of ocean acidification for biogenic calcifiers are of paramount concern in tropical coral reef ecosystems. We conducted field and laboratory manipulations on Palmyra Atoll to explore the influence of natural pH variability and experimentally elevated pCO_2 on recruitment, growth and mechanisms of carbon acquisition in crustose coralline algae (CCA), important reef builders in most coral reef ecosystems. Recruitment plates were used to track early succession of benthic algal communities, change in CCA buoyant weight following 4 and 10 months of exposure to natural pH variability was used to estimate calcification rates, and tissue from CCA rhodoliths was assayed for total carbonic anhydrase activity. These measurements were made across six sites on the shallow reef terrace that experienced drastic shifts in diurnal pH (~0.2) and four sites on the exposed fore reef that experienced more stable pH (~0.1). pH and temperature were monitored continuously with autonomous SeaFET sensors and were calibrated by periodic water sampling for carbonate chemistry. Using the long-term *in situ* record of pH at the 10 sites on Palmyra, we correlated pH variability with variability in recruitment, growth, calcification and carbonic anhydrase activity for each species of CCA. Finally, we conducted controlled laboratory manipulations to elucidate the effects of elevated pCO_2 (~900 µatm) on growth and carbonic anhydrase activity in the CCA *Lithophyllum sp.* These findings provide insight into the mechanisms of carbon acquisition in some CCA, and the role that carbon concentrating mechanisms may play in shaping the response of calcified algae to ocean acidification.
8D Effects of ocean acidification
Wednesday 11 July, 1715, MR5

Diverse responses of coral reef organisms to ocean acidification

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Coral reef biodiversity is extremely high and interactions between organisms are essential to maintain the dynamic equilibrium of the ecosystem. Several studies demonstrate that ocean acidification intricately impacts marine organisms at different levels and ways, which suggest that there will be some 'winners' and 'losers' in the future ocean. However, on coral reefs, most of the ocean acidification studies are principally focused on corals, which may not be sufficient to understand its effect on ecosystem level. In this present study, we will report our several ongoing studies evaluating the impact of ocean acidification on several different taxa including scleratinian corals, sea urchins, sea star, giant clam, sea grasses and coral reef fishes. Response diversity between species, stages and effects on the interaction between species will be focused on. Additionally, interactive effects between other environmental factors such as temperature and sunlight conditions on the organism's response to the ocean acidification will be discussed. Finally, ecological interpretation of the climate change on the coral reef ecosystem will be suggested.

8D Effects of ocean acidification
Wednesday 11 July, 1445, MR5

Carbonate chemistry at CO_2 seeps in Papua New Guinea

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Cool CO_2 seeps in Papua New Guinea provide a natural laboratory for observing the consequences of long-term exposure to elevated CO_2 on natural coral reef and seagrass communities. Three sites designated Dobu, EsaAla and Upa-Upasina were surveyed in Aug 8-17, 2010 and Apr 23-May 1, 2011. High-resolution maps of pH were prepared for each of the sites by towing a pH sensor just above the bottom from a small boat while running transects parallel and normal to the shoreline. Discrete water samples were collected at the top

and bottom and were analyzed for TA, DIC, pH and Ca^{2+}. The mapping revealed zones of reduced pH (pH<7.9) associated with the fields of bubble streams extending 265-350 m parallel to the shore and 160-220 m normal to the shoreline. There was a small but measurable difference in pH (~0.25 units) between the surface and the bottom indicating a fairly rapid dissolution of the CO_2 gas into the water column balanced against mixing processes. DIC ranged from 1918 at the fringe of the impact zone to 2924 umol/kg within the center of the densest bubble streams and TA ranged from 2240 to 2594 umol kg^{-1} along the same gradient. [Ca^{2+}] was 9.9±0.1 mmol kg^{-1}. pCO_2 ranged from 600-14060 µatm, pH (total scale) 6.67-7.89 and Ωar 0.25-3.01 and median values were 3310 µatm, 7.24 and 0.84, respectively. The next important step is to characterize the temporal variability that the organisms living in the impact zone experience on time scales from hours to months.

8D Effects of ocean acidification
Wednesday 11 July, 1400, MR5

Light, flow, and ocean acidification: interactive effects on cnidarian growth

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Increased carbon dioxide levels in the atmosphere caused by the burning of fossil fuels is the source of increasing carbon dioxide in the ocean and the resulting decreases in oceanic pH and aragonite saturation state. These decreases are predicted to detrimentally affect the abilities of corals to produce calcium carbonate skeletons. It was hypothesized that these negative effects could be mitigated by other environmental conditions. A laboratory experiment was carried out to determine if any combinations of light levels and water flow rates have the ability to minimize the effects of ocean acidification on the growth of a variety reef cnidarians. Eighteen treatments, consisting of two pH levels (8.1 and 7.8), three water flow rates (5, 15, and 25 cm/s) and three light levels (45, 85, and 165 micromoles per second per square meter per microangstrom) in a fully crossed design were tested. Changes in mass/living surface area and changes in complexity were monitored during each three month experiment. Initial studies of *Pocillopora damicornis* showed that individuals of this species exposed to flow rates of 15 cm/s did not exhibit significant changes in growth under changing water chemistry conditions. This was true for all light conditions. However, individuals in low and high flow conditions showed significant decreases in growth under multiple lighting treatments. Healthy *P. damicornis* dominated reefs that have average flow conditions of approximately 15 cm/s should be considered as candidates for protection, as they are likely to continue to show consistent growth rates as ocean acidification continues.

8D Effects of ocean acidification
Thursday 12 July, 1030, MR5

Coral reef calcifiers under elevated CO_2 and organic matter availability

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Coral reefs worldwide are affected by both ocean acidification (OA) and increased availability of nutrients, through human activities. However, experimental studies on the interplay of these two factors are missing, but are needed to understand synergistic effects and their contribution to phase shifts from coral to algae dominated reef communities. This combined laboratory and field study investigates the impact of OA with elevated dissolved organic matter (DOM) availability both on the organism and community level using model shallow reef calcifying organisms. Under these stressors, individual responses (ontogeny, calcification, photosynthesis, respiration, nutrient fluxes) of corals, green algae and herbivores will be measured and species interactions and community responses will be determined. We hypothesize that the effects of OA and increased DOM availability will reduce algal and coral fitness and growth, while altering calcification and organic carbon fluxes with implications for coral algal competition and bacterial activity. Grazers may be affected by altered calcification and reduced recruitment rates. Here we present first results of experiments at the organism level and discuss the outcomes regarding potential impacts on species interactions and community effects. Supplementary experiments with coral and herbivore larvae will increase the knowledge of species responses as larval stages are considered a bottleneck in the susceptibility to OA. Mesocosm investigations on the interaction of all model species will conclude this study and contribute to the understanding of phase shifts and functioning of future coral reefs, in which the production and the cycling of organic matter is likely to change.

8D Effects of ocean acidification
P082

Response of coral symbiosis to ocean acidification and thermal stress

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Ocean acidification (OA) research, in regard to coral, has primarily focused on calcification. This study focuses on the synergistic effects of OA and increased temperature on photosynthetic processes of the algal endosymbiont, *Symbiodinium*, and the response of the coral host. *Acropora aspera* were subjected to changes in both CO_2 and temperature to simulate conditions expected to occur in the next

30-50 years. Nubbins were exposed to ambient CO_2 and elevated CO_2 (50-100 ppm above ambient), with each CO_2 level subjected to ambient temperature (26-29℃) and 30-32℃ for 14 days. Over the course of the experiment the response of both the *Symbiodinium* and coral were measured. Photosynthetic efficiency of *Symbiodinium* was monitored using pulse-amplitude modulated (PAM) fluorometry along with chlorophyll levels, *Symbiodinium* density and expression of genes related to photosynthesis and/or stress response (i.e. rubisco, carbohydrate transporters, and heat shock proteins). For the coral host the gene expression of antioxidant enzymes and heat shock proteins was determined, along with *in situ* localisation and western blots of three carbonic anhydrases. Visible bleaching occurred in both heated treatments after four days, which coincided with a sustained decrease (approximately 20% lower than ambient temperature treatment) of photosynthetic efficiency. Surprisingly, corals exposed to elevated CO_2 had a higher photosynthetic efficiency than those heated nubbins at ambient CO_2. This study shows that both the coral and *Symbiodinium* are affected by temperature and elevated CO_2.

8D Effects of ocean acidification
Wednesday 11 July, 1530, MR5

Increased temperature and pCO_2 effects on ten Caribbean coral species.

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To compare the responses of Caribbean corals to climate change, ten common species are growing in a crossed elevated temperature and pCO_2 experiment. Calcification, photosynthetic efficiency, zooxanthellae composition, and total lipid content will be measured to gauge how different components of the coral holobiont respond. Treatments consist of two temperatures (control: 27℃ and sub-bleaching stress: 30℃) and three pCO_2 levels (control: 390 ppm and elevated: 800 ppm, 1200 ppm). Previous work indicates corals may suffer tradeoffs between stress tolerance and calcification, which this study will further explore. We hypothesize stress-tolerant species will have lower overall calcification rates but more consistent lipid levels across treatments than other species. This experiment will also clarify whether ocean acidification is a physiological stress in addition to a chemical stress. If ocean acidification is purely a chemical stress, calcification rates will decline with rising pCO_2 while health indicators such as lipids should remain constant. Furthermore, relative rates of decline should be consistent across all species. This experiment will provide data on understudied species with results applicable to biologists, managers, and climate modelers.

8D Effects of ocean acidification
Wednesday 11 July, 1515, MR5

Ocean acidification affects community structure of crustose coralline algae

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Crustose coralline algae (CCA) are among the most sensitive group of calcifying organisms to ocean acidification. Processes such as calcification, growth and recruitment are severely affected by reduction in pH and changes in carbonate chemistry. However, the effects of ocean acidification on the structure and composition of CCA communities have not been investigated. The aim of this study was to explore potential shifts in the species composition of the CCA community in response to increased levels of carbon dioxide and associated ocean acidification. The cover, density, species richness and composition, as well as the number of reproductive structures (conceptacles) per individuals of CCA that recruited on aquarium panels was evaluated across three levels of CO_2 concentration. The CO_2 treatments included a control (present day, 389 ± 6 ppm CO_2), medium (753 ± 11 ppm CO_2) and high (1267 ± 19 ppm CO_2). We found that ocean acidification negatively affected the abundance and density of several species of CCA, and the number of conceptacles. Community composition also shifted, with assemblages of lower species diversity occurring under the high CO_2 treatment. The observed changes in abundance and diversity support the idea that CCA are a highly sensitive group to the effects of increased CO_2 levels. Given that CCA play important roles in reef ecology, such changes could potentially have follow-on effects on coral reef ecosystems.

8D Effects of ocean acidification
Wednesday 11 July, 1730, MR5

Roles of biogeochemical processes in coralline-algae dissolution under climate change

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Crustose coralline algae (CCA) play fundamental roles in the cementation of reef frameworks by depositing high magnesium calcite. Interactions of elevated temperature and pCO_2 not only reduce the calcification of CCA, but also cause carbonate dissolution. While increased skeletal dissolution of

CCA has been related to changes in seawater carbonate chemistry and abundance of endolithic algae, little is know about the contribution of each component to the dissolution processes under projected climate change scenarios. To address this issue, live and dead fragments of the CCA *Porolithon onkodes* were exposed to a range of climate change scenarios predicted by the IPCC (including B2: + 220 ppm CO_2 and 2.4°C , and A1FI: + 600 ppm CO_2 and 4°C) in Heron Island, Great Barrier Reef, Australia. To isolate the effects of water chemistry (carbonate saturation state) from the contribution of endolithic algae to CCA dissolution, live and dead CCA substrates were placed under natural light and full dark conditions. Our preliminary results indicate that future climate change scenarios may increase the dissolution of live and dead CCA substrates. Both the erosion caused by endolithic algae and the dissolution promoted by undersaturated states of high Mg calcite contributed to the total skeletal losses of CCA. We suggest that the interactions between ocean acidification and warming and endolithic algae may intensify the rates of dissolution on calcifying algae, potentially disrupting several key processes in coral reef ecosystems.

8D Effects of ocean acidification
Wednesday 11 July, 1700, MR5

Quantifying ecosystem calcification responses to elevated CO_2 on coral reefs

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Single and multi-organism laboratory-based CO_2 manipulation experiments show that calcification by most coral reef calcifiers is negatively impacted by ocean acidification. However, extrapolation of experimental data to real reef systems is challenging because multiple parameters affect calcification of coral reefs such as light, temperature, nutrients, and organic production. To date, the net ecosystem calcification (NEC) response to changes in seawater pCO_2 has been investigated for just a handful of coral reefs. While the NEC response to increasing CO_2 has been shown to be negative, the current paucity of data limit our ability to predict the specific trajectory of individual reef systems, in particular, the pCO_2 or aragonite saturation state (Ωarag) where net dissolution exceeds net calcification. We quantified NEC rates of multiple Pacific reefs by tracking changes in total alkalinity (TA) as water moved across the reef. The natural spatial and temporal variability of reef seawater CO_2 was quantified and used to establish the sensitivity of NEC to changes in CO_2. Although NEC and CO_2 were negatively correlated within individual reef systems, the relationship is not straightforward. For example, the barrier reef of Kaneohe Bay, Hawaii is characterized by significantly higher CO_2 and lower Ωarag than Eilat Reef in the Red Sea, yet rates of NEC are significantly higher in Kaneohe Bay. These results indicate that additional factors interact to modulate the impact of Ωarag on ecosystem level calcification. Using new data, we explore the role of nutrients in maintaining NEC rates in coral reef with varying pCO_2 levels.

8D Effects of ocean acidification
Thursday 12 July, 0930, MR5

Tropical CO_2 seeps: effects of ocean acidification on benthic foraminifera

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Shallow water CO_2 seeps in east Papua New Guinea are ideal proxies to investigate changes in coral reef communities due to ocean acidification under CO_2 concentrations predicted for the end of this century. Here we present data from benthic foraminiferal distribution and photophysiological studies around 3 seeps. Benthic foraminifera in sediment samples of control areas (present day pCO_2, ~ 380-450 µatm) are diverse (up to 30 taxa per sample) and abundant. Species numbers and density drastically decrease at near future CO_2 concentrations (pHTotal 7.8-7.9, 600-800 µatm pCO_2). In areas of only slight CO_2 increase most specimens showed signs of shell corrosion. This suggests that some species may exist in micro-niches (e.g. on algae elevating pH in benthic boundary layers) but do degrade once they become detached. One symbiont-bearing species (*Marginopora vertebralis*) epiphytic on seagrass was studied in further detail. This foraminiferal species is absent in seagrass beds near impacted sites at pH levels <7.9. Respiration rates of that species increased significantly with increasing pCO_2 concentrations. Oxygen production of the symbiotic dinoflagellates (measured in 24 h *in situ* incubations) increased significantly when pH levels were lowered by more than 0.2 units. Thus, endosymbiotic algae may benefit from increased dissolved inorganic carbon availability in the short term. Nevertheless, foraminifera cannot exist at enhanced pCO_2 conditions. Abundances of all taxa and trophic levels (heterotrophs vs. those in association with photosynthetic symbionts) were negatively affected by high CO_2. These findings paint a bleak picture for the future existence of these important carbonate producing protists.

8D Effects of ocean acidification
Wednesday 11 July, 1415, MR5

8E Growth records in coral cores

Assessing the dominant controls on coral growth: implications for reef responses to climate change

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Accurate predictions of coral reef responses to global climate change are currently limited by a lack of knowledge of the dominant environmental controls on coral growth. Corals exhibit significant responses to environmental variability occurring on multi-annual to decadal timescales, which are significantly longer than the duration of typical laboratory and field-based experiments. Skeletal growth records, which provide annually-resolved histories spanning several centuries, enable links to be established between coral growth and both long-term trends and low-frequency oscillations in environmental conditions. We used 3-D CT scan and imaging techniques to quantify growth of 2 species of massive Atlantic corals over the last 2 centuries. In the central tropical North Atlantic (US Virgin islands), sea surface temperature (SST) exerts the dominant control on coral growth on multi-annual timescales. Here, the 1°C increase in average annual SST since 1900 AD has driven a ~30% increase in the annual growth of *Siderastrea siderea,* a keystone species in the Caribbean. Conversely, in the western subtropical Atlantic (Bermuda), growth rates of the dominant massive coral *Diploria labyrinthiformis* have decreased by 25% over the last 50 years. Here, we find that primary productivity - indicated by chlorophyll A - and not SST, is the primary driver of coral growth. Our results are consistent with previous observations of variability in coral responses to 20th century CO_2 driven climate change. Importantly, our study points to the possible mechanisms underlying this variability and implies that climate change impacts on primary productivity must be considered in projections of coral reef futures.

8E Growth records in coral cores
Thursday 12 July, 1715, MR5

Surviving coral bleaching events: *Porites* growth signatures

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Mass coral bleaching affected large parts of the Great Barrier Reef (GBR) in 1998 and 2002. In this study, we assessed what, if any, signature of these major thermal stress events were recorded in the growth characteristics of massive *Porites* colonies. In 2004 and 2005 a suite of short (<50cm) cores were collected from apparently healthy *Porites* colonies from four reef sites in the central GBR (18-19°S). These range from inshore (Nelly Bay, Pandora Reefs) sites annually affected by freshwater flood events, a midshelf site (Rib Reef) only occasionally affected by freshwater floods and an offshore site (Myrmidon Reef) primarily exposed to open ocean conditions. Annual growth characteristics (extension, density and calcification) were measured in 142 cores from 79 coral bommies and analysed over the common 21-year period, 1983-2003. Visual examination of the appearance of the annual density bands on X-rays of the coral slices revealed growth hiatuses associated with the bleaching years in some corals at some sites. Linear extension and calcification rates were suppressed for 4-5 years at the two inshore sites after the 1998 event, followed by recovery to normal rates. No significant effects on growth rates were evident at the mid shelf and offshore sites, nor on skeletal density. Examination of the skeletal structure in affected corals provided further insights into the growth responses to thermal stress events and characteristic signatures of such events in massive *Porites* corals.

8E Growth records in coral cores
Thursday 12 July, 1500, MR5

How do historical background conditions affect the coral bleaching threshold?

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Coral cores provide a useful record of the response of individual corals to past heat stress events. By comparing the responses of corals that experience different background conditions to the same heat stress events, we have investigated how background conditions affect the coral bleaching threshold. We will present results from two island groups in the central Pacific: the Gilbert and Line Islands. In the Gilbert Islands, the main differences between sites is the background thermal variability gradient; sites closer to the equator experience higher year-to-year thermal variability due to the El Nino Southern Oscillation. The Line Islands also experience a thermal variability gradient, but in addition three of six islands are unfished, while the other three are moderately fished by the local population. We will present evidence from the Gilbert islands based on coral growth rates from cores as well as lipid class analyses from tissue samples of massive *Porites sp.* corals that suggests pre-exposure to heat stress increases the likelihood of corals resisting bleaching during subsequent heat stress events. This finding expands the applicability of results from previous lab- and survey-based studies investigating the influence of thermal history

on subsequent coral bleaching. We will also present results from cores from the Line Islands investigating whether moderate fishing significantly affects the coral bleaching threshold, possibly through alteration of nutrient cycling on the reef.

8E Growth records in coral cores
Thursday 12 July, 1515, MR5

Growth of Australian corals in the Anthropocene: all quiet on the western front

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Anthropogenic increases of atmospheric CO_2 lead to increased sea surface temperatures (SST) and altered ocean chemistry. Experimental evidence suggests that coral calcification decreases with reduced pH and aragonite saturation, but increases with temperature up to a threshold. *In situ* studies of coral growth have documented a recent decline in coral calcification rates on several tropical coral reef ecosystems, which have set alarm bells ringing of an imminent crisis in calcification on coral reefs. This talk will present findings of a large-scale coral coring project that show that calcification rates in massive *Porites* have not declined significantly over at least the past century on coral reefs spanning 11° latitude in the south east Indian Ocean (Western Australia). Indeed, calcification rates increased during the 20th century on the high latitude reefs of Western Australia in contrast to the downward trajectory reported for corals on Australia's Great Barrier Reef (GBR). The increase in calcification rates in the high latitude reefs of Western Australia, which have not experienced the same severity and frequency in bleaching events as tropical reefs in the region, provide additional evidence that recent changes in calcification rates on tropical coral reefs are responses to thermal changes rather than ocean acidification

8E Growth records in coral cores
P083

Are skeletal growth parameters predictors of coral thermal stress tolerance?

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During the mass bleaching event of 2005, *Montastraea annularis*, a dominant Caribbean reef-building coral, suffered significant mortality at multiple locations. Conversely, *Solenastrea bournoni* was not affected. To uncover the reasons for these different responses, we quantified skeletal growth parameters of surviving colonies of each species during the years leading up to and following the bleaching event. 30-year records of skeletal density, linear extension rate, and calcification rate were generated from 3-D CAT scan images of cores extracted from multiple colonies. High density stress bands were evident in the CT images of both species within the 2005-2006 growth year, demonstrating that both species responded to the thermal anomaly. However, different relationships between skeletal growth and sea surface temperature (SST) were observed. Linear extension and calcification of *M. annularis* was strongly positively correlated with SST. Calcification increased by 0.152 g cm^{-2} per 1 °C over the last 30 years. Conversely, skeletal growth by *S. bournoni* was negatively correlated with SST. Calcification declined by 0.006 g cm^{-2} per 1 °C. The skeletal data, which imply *M. annularis* is more thermally tolerant than *S. bournoni*, are in apparent contradiction to the bleaching outcome, which showed *M. annularis* is less tolerant. However, our observations are likely explicable in terms of a classic trade-off between growth rate and tolerance to thermal stress. Subsequent analyses, including identification of zooxanthellate clades, are used to test this hypothesis. If verified, our results have important implications for the use of skeletal data in the identification of thermally tolerant coral species.

8E Growth records in coral cores
Thursday 12 July, 1745, MR5

High-resolution analysis of daily growth bands in giant clams

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Giant clams live in shallow sea areas (coral reef) of the Indo-Pacific region and in symbiosis with zooxanthellae. The shells of a giant clam *Hippopus hippopus* form daily growth bands and grow very rapidly (> 1 cm/year). Therefore, we expected to extract high-resolution (weekly to subdaily) oceanographic and climatic records at their growth sites. However, few rigorous analyses on daily growth increments have been conducted. Here, we present analytical results of the daily growth increments of *H. hippopus* shells collected in Ishigaki-jima, southwestern Japan. The daily growth increments, ranging from ~7 to ~71 μm/day, show annual cycles; summer increments are larger than winter increments. The daily growth increments are correlated significantly with sea surface temperature (SST) and global solar radiation. There are strong correlations between variations in the daily growth increments smoothed with 7-day and 31-day moving average window and those in SST and global solar radiation. It is shown that negative anomalies in the daily growth increments commonly correspond to abrupt, large decrease in SST and global solar radiation and increase in precipitation.

These results indicate that *H. hippopus* shells can be used as an excellent proxy of seawater temperature and global solar radiation.

8E Growth records in coral cores
P084

Variability of the Leeuwin Current over the past 250 years

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The Leeuwin Current is the driving force behind complex physical environments and marine ecosystems of the west and south Australian coasts. Variability in this system will result in large-scale changes not only in biodiversity, but also reflected in the physical aspect and organization of WA coastal environments. The Leeuwin Current nurtures exceptional environments such as Ningaloo reef (second largest fringing coral reef in the world) and Shark Bay, a world heritage listed site. The current follows a large-scale meridional pressure gradient in the southeast Indian Ocean and is largely fed by the Indonesian Through Flow (ITF). Each year the Leeuwin Current's strength is influenced by ENSO-related thermocline anomalies inducing clear seasonal variation. We have investigated the past 250 years radiocarbon record of a coral core collected from Rowley Shoals (Western Australia) as a thermocline proxy of the variability of the Leeuwin Current. The high-resolution radiocarbon record (200 years prior to the ocean bomb spike and 40 years after) were extracted using state-of-the-art AMS ANTARES at the Australian Nuclear Science and Technology Organisation (ANSTO) and linked to environmental data obtained by measurements of $\delta^{18}O$ variation and Sr/Ca ratio of the same coral core. The outcomes of the entire project will result in accurately predicting and responding to future changes by adequately designing conservation strategies to increase resilience of the marine ecosystems.

8E Growth records in coral cores
Thursday 12 July, 1750, MR5

No sympathetic temporal trends of temperate coral calcification rate

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We will show no consistent temporal trend in coral calcification for temperate reefs in North-West Pacific, Japan. Oceanographic data sets collected by direct measurements Indicate that the mean annual sea surface temperatures (SSTs) in this region have increased by 1.3/100 year, which is much faster warming than has been observed in the global tropical and subtropical regions (0.4 and 1/40 year). Along with this warming trend, aragonite saturation states have decreased at a rate of -0.12±0.05/10 year (1994-2008) in surface water off the south coast of Honshu, Japan. We used coral cores collected from *Porites spp.* colonies from reef sites located at Kushimoto (33°N, 135°E), Tatsukushi (32°N, 132°E), Koshiki Island (31°N, 129°E), Ishigaki Island (24°N, 124°E). Calcification rates were generated using non-destructive transparent X-ray 2-D imaging scanner (TATSCAN-X1). The time series analyses were performed using a generalized state space model with Bayesian inference and Markov Chain Monte Carlo method. Our results indicate that coral calcification has not consistently increased or decreased amongst various sites due to the effect of global warming and ocean acidification. Coral calcification rate increased at Tatsukushi (*P. lutea*, 1985 - 2006), decreased trend at Koshiki Island (*P. heronensis*, 1940 -2007), and remained relatively constant at Kushimoto (*P. lutea*, 1967 -1999). We will investigate the influence of oceanographic factors on coral growth (calcification, annual extension rate, skeletal density), and further discuss the potential for recent adaptation of temperate corals in relation to the future prospects of coral calcification.

8E Growth records in coral cores
P085

Coral records of 20th century central tropical Pacific SST and salinity

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Coral skeletal geochemistry has provided high fidelity climate records of El Nino/Southern Oscillation (ENSO) whose extremes events challenge the management of coral ecosystems via anomalous sea-surface temperature (SST) and hydrology. Coral oxygen isotopic composition ($\delta^{18}O$) reflects changes in SST and seawater $\delta^{18}O$ ($\delta^{18}Osw$), the latter linearly related to salinity. A millennium-long compilation of living and fossil coral $\delta^{18}O$ records from the central tropical Pacific (CTP) exhibits a late 20th century trend toward negative coral $\delta^{18}O$ values, suggesting warming and/or freshening conditions in a warming climate. Here, we present coral-based SST and salinity records from the CTP over the 20th century, via combined coral $\delta^{18}O$ and Sr/Ca (a SST proxy) measurements to derive changes in $\delta^{18}Osw$ as a salinity proxy. On interannual timescales, the SST record tracks both eastern- and central-Pacific flavors of ENSO variability. Interannual salinity variability in the $\delta^{18}Osw$ record highlights profound differences in

precipitation and ocean advections during the two flavors of ENSO. Decadal-scale SST variations in the CTP are highly correlated to the recently discovered North Pacific Gyre Oscillation, whereas salinity variability is linked to the Pacific Decadal Oscillation. The most prominent feature of the new coral records is an unprecedented freshening trend since the mid-20th century, in line with global climate models projections of enhanced hydrological patterns (wet areas are getting wetter and vice versa) under greenhouse forcing. Taken together, the coral records provide key constraints on tropical Pacific climate trends that may improve climate change adaptation strategies in areas affected by tropical Pacific climate variability.

8E Growth records in coral cores
Thursday 12 July, 1740, MR5

A 1000-yr record of coral calcification (*Goniopora*) from the GBR

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Coral calcification is sensitive to changes in both sea surface temperature (SST) and aragonite saturation state. However, in a world of concurrent climate and human associated stressors on coral reefs, it is important to understand the degree to which multiple human stressors modify sensitivity of calcification to climate change. We examined *in situ* coral growth over a millennium time-scale using colony fragments of the dominant taxon, *Goniopora*, that were derived from reef matrix cores from Pandora and Havannah reefs within the Palm Island Group on the inshore Great Barrier Reef (GBR). We measured calcification during the past 865 years, and compared results from four inclusive periods: Pre-history (1140 to 1862), Post European Colonisation (1863 to 1944), Industrialisation (1945 to 1974), and Recent (1975 to 2005). Calcification of 400 samples was determined from digitised x-radiographs through optical densitometry. Calcification was inversely correlated with temperature prior to, but not after, European colonisation of the Queensland coastline. Surprisingly, calcification increased over the past several decades, contrary to studies of predominately autotrophic corals, such as *Porites*. We conclude that while temperature is a major driving factor in calcification, effects can be masked when acting in concert with other drivers. Increasing SST combined with increasing river discharge over the past 40 years has enhanced calcification in *Goniopora* on inshore reefs of the GBR. Moreover, increased heterotrophy in corals might mediate both the sensitivity and direction of the response of calcification to climate change, especially in coastal environments exposed to increased turbidity or nutrient flux.

8E Growth records in coral cores
Thursday 12 July, 1630, MR5

Salinity effect on skeletal chemical composition in cultured zooxanthellate corals.

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This study investigates the effect of salinity on elemental and isotopic skeletal composition of modern zooxanthellate scleractinian corals to evaluate potential salinity proxies. Corals were cultured in the laboratory at different salinities (36, 38 and 40). Except for salinity, all environmental parameters were kept constant in the aquaria. Salinity variations were introduced progressively to preclude stress or mortality. Sr, U and Li to calcium ratios are not influenced by changes in salinity whichever genuses considered. The Ba/Ca ratio reveals more inter-generic variations, up to one order of magnitude, but lacking a systematic relationship with salinity. However, the Cd/Ca ratio decreases as a function of increasing salinity (R^2=-0.7). Furthermore, results show significant inter-generic variations for the Mg/Ca ratio, with implications for this proxy currently in use. $\delta^{18}O$ and $\delta^{13}C$ seem to be sensitive to salinity variations, with opposite trends. This study shows that salinity is not a significant parameter involved in the elemental incorporation into coral skeleton, except for Cd. These preliminary results confirm the reliability of the well established temperature proxies Sr/Ca and U/Ca as both ratios are immune to salinity variations. By contrast, the Cd/Ca ratio may be sensitive to salinity variations and the salinity dependence could compromise Cd/Ca as an upwelling proxy, unless corrected for with an independent salinity proxy. Regardless, if the dependence found in the preliminary dataset proves to be systematic, the Cd/Ca ratio represents a promising 'salinometer' awaiting detailed investigation.

8E Growth records in coral cores
P086

320 Years of *Porites lutea* coral growth patterns explained

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Few studies have examined coral growth patterns beyond the onset of the industrial revolution (~1850 CE); none have done so in the Andaman Sea. This study used coral extension and calcification rates of *Porites lutea* colonies at Phuket, South Thailand, over a 320-year time span (1690 - 2010 CE). Laser Ablation ICP-MS was used to determine high-resolution elemental ratios and rare earth incorporation within the growth bands. Extension rates were highly variable over time with a noticeable decrease in the last 100 yrs. Calcification rate anomalies were present in bleaching years and shortly after the Boxing day tsunami. The latter time period also exhibited spikes of element ratios, which indicate a tsunami signature. This suite of environmental proxies, combined with historical sea surface temperature and sea surface salinity data, gave us a powerful and accurate tool to explain coral calcification and growth rates and allowed us to discriminate between local pollution impacts, natural disturbances (i.e. tsunamis) and recent climate change.

8E Growth records in coral cores
Thursday 12 July, 1530, MR5

Reduced trend of annual growth of Indonesian *Porites* over 20 years

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Annual coral growth bands serve as an important indicator to detect the response of coral reefs to environmental change, through the study of coral growth chronologies and geochemical analyses of the skeleton. In this study, we analyzed the annual linear growth rate of *Porites* coral colonies from Indonesia. Samples were taken from Natuna (South China Sea), Wakatobi (Banda Sea), Maumere (Flores Sea) and Biak (Indo-West Pacific Sea). Each location was represented by three colonies that were sampled from each of the different coral reef locations. Annual growth parameters (linear extension) were determined from the annual high and low-density banding patterns observed using X-ray techniques. Coral XDS was used to calculate annual linear extension. Average linear growth of *Porites* colonies ranged from 0.4 cm to 1.4 cm /year over the past ~20 years. The results show that the *Porites* corals from Indonesia have displayed reduced linear growth over the past ~20 years. However, few colonies show increasing linear growth trend, for example colony code WDB (North Eastern Biak) and SRM (Southern Biak) and MMR4 (Maumere coast), while at Wakatobi site all the three *Porites* colony show reduced linear growth. It seems that mostly at Biak, the linear growth of *Porites* colonies shows increasing trend.

8E Growth records in coral cores
Thursday 12 July, 1730, MR5

Growth and luminescent banding in massive *Porites* from the Thai-Malay Peninsula

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A comparison of growth rates of *Porites lutea* from Phuket, South Thailand between two time periods (December 1984 - November 1986, and December 2003 - November 2005) found significant decreases in coral calcification and linear extension rates between the two sampling periods, while skeletal bulk density remained unchanged. Growth rates reductions seen in results obtained to date appeared to be driven by temperature, rather than ocean acidification, with a consistent link found between rising sea surface temperature (SST) and the reduced linear extension rates of the order of 38-46% for every 1°C rise in SST. The apparent sensitivity of linear extension in *P. lutea* to increased SST suggests that corals in the Andaman Sea may already be subjected to temperatures beyond their thermal optimum for skeletal growth. Presently, a total of 100 massive *Porites* colonies from 17 reefs around the Thai-Malay Peninsula (~1°-8°N, 98°-105°E) have been sampled and are being analysed as part of ongoing research to determine the extent of decline in coral growth in the region. The current effort is attempting to examine variation in growth rates over a larger spatio-temporal scale while including additional relevant environmental parameters (e.g. sedimentation and light). Preliminary analyses indicate much within and between site variation in growth rates, with complex luminescent banding patterns that seems to be strongly influenced by interacting monsoonal currents and hydroclimate of the Malacca straits.

8E Growth records in coral cores
Thursday 12 July, 1545, MR5

Dating reefs using amino acid racemization of coral intra-crystalline protein

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If accurately dated, coral skeletons are valuable archives of palaeo-environmental conditions. We demonstrate the value of Amino Acid Racemization (AAR) in coral skeletal protein for dating Holocene and Quaternary coral material. AAR is a time-dependent degradation process involving the inter-conversion of L-amino acids (that constitute protein in living organisms), into an equilibrium mixture of L- and D-amino acids. We apply recent methodological improvements including measurement by reverse-phase high-performance liquid chromatography, separation of the intra-crystalline skeletal protein, and strict quality control protocols. Over 500 Free Amino Acid (FAA) and corresponding Total Hydrolysed Amino Acid (THAA) analyses were completed from 8 independently-dated massive *Porites sp.* colonies, containing material from 1565 to 1985 AD. AAR values for several amino acids follow a consistent stratigraphic order within cores, with aspartic acid (which dominates coral skeletal protein) providing the best resolution. However, natural variability between colonies decreases dating resolution to, at best, ±10 years (2SD). The value of AAR for dating Holocene material will therefore be in its utility as a cheap and rapid geochronological tool for screening populations of coral samples (e.g. identifying material from mixed populations in beach or uplift deposits). We also present data showing that AAR has great potential for dating coral recording Quaternary palaeo-sea level change. Results from U-Th dated specimens (*Acropora palmata* and *Montastraea annularis*) from Barbados MIS 5-11uplift terraces demonstrate that AAR can discriminate between MIS stages and most sub-stages. In addition AAR appears unaffected by diagenetic alterations (e.g. dissolution and secondary overgrowth of the skeletal material).

8E Growth records in coral cores
Thursday 12 July, 1700, MR5

Evaluation of amino acid racemization variability in Quaternary corals

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Four Quaternary sea-level cycles are recorded in cores from Glover's Reef, a Caribbean atoll. Due to extensive meteoric diagenesis, U-series and C-14 dating techniques have failed to provide ages for these cores; however, preliminary results show that the extent of amino acid racemization (AAR) increases monotonically down core and has potential to provide independent age control. Of particular interest is a lowstand exposure horizon through a cluster of amino acid racemization values, which suggests that the two youngest Pleistocene sequences are similar in age, possibly even sub-stages of Marine Isotope Stage 5e. To assess the limitations of the technique, we explored the natural variability in AAR using different pre-treatment and subsampling strategies on three coral species. Eight different amino acids were measured in twenty-nine samples from a 60 cm section of Pleistocene *Montastraea cavernosa*. Corallite and coenosteum skeletal material were analysed separately and samples were sub-divided to compare different preparation methods. Using only coenosteum material and not bleaching samples prior to analysis results in the least intra-sample variability. Of the eight amino acids analysed, only aspartic acid, glutamic acid, and valine had strong down core trends ($r^2 \geq 0.75$). Cross-plots of the extent of AAR in aspartic and glutamic acids show strong correlations and correct stratigraphic ordering for both *Montastraea annularis* and *Acropora palmata* samples, although the species have distinct racemization rates. Future work will use dated corals from nearby localities in Belize to calibrate the rate of AAR and assess the resolution of the technique in the late Pleistocene.

8E Growth records in coral cores
P087

Physical conditions influence coral extension rates in Hong Kong

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The marine environment in Hong Kong is marginal to coral growth due to large seasonal variability. Annual variability of pH (7.4-8.7), temperature (13.9-29.8℃), salinity (27.4-35.1psu), dissolved oxygen (1.9-10.4) and turbidity (0.3-41.4NTU) are larger than most tropical reef environments. Massive *Porites* colonies grow at rates significantly below average compared to the same species from non-marginal environments (3.9 and ~15 mm/yr respectively). With no evidence of reef accretion now or in the past, the large variability in environmental conditions is suspected to limit growth in this region. Six coral cores were sampled from three distinct marine environments in Hong Kong waters; namely Crescent (northeast), Pak Lap (east) and Lamma (south). In order to evaluate which factors contribute most significantly to low coral growth, we statistically evaluated the relationship between inter-annual coral extension rates and a range of physical and biological factors from each site. Our results show that coral extension of each colony is dominated not by a single environmental condition, but by different combinations of nutrient and chlorophyll a levels (indicative of food supply) as well as physical conditions including temperature, salinity, turbidity and dissolved oxygen. Each coral colony appears to respond independently to their changing environment. The low extension rate and the wide range of conditions both seasonally and geographically in Hong Kong indicate that these corals, though stressed, are able to survive in

waters with several environmental gradients outside the normal range found in thriving coral reefs ecosystem.

8E Growth records in coral cores
Thursday 12 July, 1735, MR5

Reef-scale temperature and growth relationships in the southwestern Indian Ocean

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We present several 50-350 year long geochemical records (Sr/Ca, Mg/Ca, stable isotopes) from the southwestern Indian Ocean with monthly to annual resolution in order to unravel natural changes in reef-scale sea surface temperatures (SST) and their relation to coral growth parameters. We assessed interannual and decadal changes in SST and if they relate to typical frequencies observed in the coral growth parameters. Our results indicate a positive growth response to increasing SST during the 20th century in the western Indian Ocean, yet with substantial decadal variability. In certain cases the growth response might have impacted the geochemical proxies incorporated into the coral carbonate.

8E Growth records in coral cores
Thursday 12 July, 1645, MR5

Theme 9. Climate change & bleaching

9A Coral bleaching & climate change

Bleaching of coral reefs in Agatti Island of Lakshadweep, India: a window view

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Lakshadweep is an archipelago of coral islands consisting of 12 atolls, 3 reefs and 5 submerged banks scattered in the Arabian Sea (8°N-12°N latitude and 71°E-74°E longitude) and this region is well known for its coral diversity. The present study surveyed coral bleaching at the Agatti Island, which covers a reef area of about 17.50 km^2. Under water surveys were carried out during January to June, 2010, adopting snorkelling and scuba methods. Elevated sea surface temperature (SST) of this region exceeded the seasonal average and a delayed onset of the monsoon triggered a widespread coral bleaching event. Maximum SSTs of up to 34°C were recorded during this period. The Agatti reefs showed an average of 73% of bleached corals along with bleaching of the associated organisms like sea anemones (87%) and giant clams (83%). The mass mortality of coral has ecological and socio-economic implications as this ecosystem is the central attraction, the source of fisheries and other ornamental organisms. This study highlights an urgent need for continuous monitoring of coral reefs of Lakshadweep islands.

9A Coral bleaching & climate change
Tuesday 10 July, 1500, Plenary Hall 2

Symbiont displacement in reef corals in an era of global change

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Reef corals generally exhibit specificity in their associations with *Symbiodinium*, but are also subject to symbiont displacement, in which atypical symbionts can become dominant in response to environmental change or disturbance. Despite considerable research, the drivers, tradeoffs and longevity of symbiont displacement are not well understood, and there is no unifying explanation for why displacement is more common in some coral taxa and environments. I hypothesize that temporal variability in total symbiont density drives the capacity of coral colonies to experience displacement, with coral bleaching representing the extreme (and most studied) example of this process. Predicting the capacity of corals to experience changes in their symbiont communities depends on both site-specific environmental variability and the host-specific ability of corals to regulate their symbionts. Coral taxa which tightly regulate symbiont densities, or which are bleaching resistant, will seldom experience displacement and will appear highly specific, especially in stable environments. In contrast, corals which only loosely regulate symbiont densities, or which are susceptible to bleaching, will be vulnerable to displacement, particularly in unstable environments. Furthermore, if coral colonies share a common pool of displacement symbionts, the community dynamics of symbionts on reefs will exhibit characteristics of complex adaptive systems. This hypothesis unifies different areas of research, including: (1) variation in host thermotolerance; (2) environmental history; (3) symbiont population dynamics; and (4) symbiosis specificity. It may help explain why coral resilience to global change stressors is likely to be site- and taxon-specific, context-dependent (i.e., influenced by neighbouring organisms), and characterized by threshold effects.

9A Coral bleaching & climate change
Wednesday 11 July, 1630, Plenary Hall 2

Interactions between bleaching and white syndrome on the Great Barrier Reef

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Coral bleaching and disease are two of the key stressors driving changes in coral cover, and both are expected to increase with the effects of climate change. One of the key unanswered questions is how these two stressors interact reciprocally to influence the incidence, susceptibility, and severity of these events. Using data from the AIMS Long Term Monitoring Program, the incidence of bleaching and white syndrome was studied on the reef slope to determine whether statistical models incorporating bleaching can help to improve predictions of white syndrome, and vice-versa. In addition, the commonly used predictors of mass bleaching on the reef flat were investigated for their predictive value for intensities of bleaching on the reef slope. The performance of these models was quantitatively assessed with respect to false positives, false negatives, and overall model skill. Furthermore, patterns of bleaching and white syndrome on the GBR as monitored by the LTMP were investigated for spatial clustering, as one would expect for an infectious disease. Neither bleaching nor white syndrome proved to be useful reciprocal predictors, and the usual predictors of mass bleaching did not predict bleaching in this dataset with much skill. Bleaching and white syndrome events were not correlated, and there were few instances of spatial clustering. In summary, interactions between white syndrome and bleaching may be more complex and subtle than would be expected from observations of co-occurrence during instances of mass bleaching or disease outbreaks.

9A Coral bleaching & climate change
Wednesday 11 July, 0945, Plenary Hall 2

Upwelling mitigates coral bleaching in the Colombian Caribbean

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The first moderate coral bleaching event for decades in Tayrona National Natural Park (Colombian Caribbean) was observed between November and December 2010. The local coral communities were also influenced by seasonal upwelling that decreased water temperatures from 28°C to 21°C from December 2010 until February 2011. Patterns of coral bleaching were compared before and after upwelling at an upwelling-exposed and -sheltered site in Gayraca Bay. Findings revealed that bleaching was more pronounced at the sheltered sites with 34% of all scleractinian corals being affected compared to only 8% at the exposed site in December 2010. By April 2011, almost all previously bleached corals (97%) at the upwelling-exposed site had recovered from bleaching. In contrast, only 77% of bleached corals had recovered at the upwelling-sheltered site and 12% had died. These results support the hypothesis that seasonal upwelling mitigates coral bleaching and facilitates recovery, however the causal environmental factors have not being identified so far. Continuous temperature monitoring in high temporal resolution did not reveal any significant differences between sites. Future research should therefore focus on the water current regime in order to assess potential key influences on coral reef functioning in Tayrona National Natural Park.

9A Coral bleaching & climate change
Tuesday 10 July, 1515, Plenary Hall 2

Molecular response associated with thermal tolerance in the reef-building coral *Acropora millepora*

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Thermal history is a critical factor in the susceptibility of corals to bleaching; an understanding of thermal acclimatization is critical in the context of global climate change. This work identifies genes differentially expressed in association with thermal preconditioning in *Acropora millepora*. *Acropora millepora* nubbins were exposed sub-bleaching heat stress for 10 days prior to a thermal challenge of 31°C. The transcriptional response of the host was profiled using cDNA microarrays. Dinoflagellate and bacterial communities were examined using 16 rRNA and ITS2 DGGE, respectively. Thermal preconditioning conferred resistance to bleaching; the symbiont density did not change through an 8 day thermal stress challenge, whereas a non-preconditioned treatment resulted in significant bleaching. Thermal tolerance was not associated with a change in the type of *Symbiodinium* or bacteria harbored by the corals, as shown by DGGE. Our experiments detected a transcriptional response associated with thermal tolerance in preconditioned corals, distinct from that of non-preconditioned corals. Differentially expressed genes included homologs of mannose-binding lectins, ferritin, and transcription factor AP-1. Additionally, we explored the molecular response to thermal injury over the course of 8 days of thermal challenge. This is the first work revealing a transcriptional response associated with bleaching resistance, illuminating mechanisms potentially involved in symbiosis stability. The acclimation response of corals to thermal stress is an important consideration when predicting the future of reefs.

9A Coral bleaching & climate change
P088

Turning up the heat: increasing temperatures and recent bleaching at the Abrolhos Islands

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Coral reefs face increasing pressures particularly when on the edge of distributions, like the Houtman Abrolhos (Abrolhos). Long-term sea surface temperature (SST) data indicates an increasing trend since the 1950's of 0.168°C/decade. This increase has been greatest in the austral winter (Jun-Aug) at a rate of 0.293°C/decade, followed by autumn (Mar-May) at 0.22°C/decade. Spring (Sep-Nov) and summer (Dec-Feb) SST has increased at a slower rate of 0.102°C/decade and 0.06°C/decade, respectively. We report the first recorded bleaching event at the Abrolhos in the austral summer of 2011. Large extents of the reef system across all island groups suffered bleaching. High frequency temperature logger data from 7 sites indicate that time-temperature thresholds are relatively low for Abrolhos (compared to other high latitude reefs). Since 2008, pooled (all 7 sites) mean daily temperatures (MDT) did not exceed 25.4°C (and only reached this for 1 day) over the austral summer and autumn (Dec-May). However, during 2011 the pooled MDT exceeded 25.4°C for 57 days (between Dec-May) reaching a high of 28.4°C (experienced for 3 days). Of the 7 sites monitored at

the Abrolhos, the hottest site (Southern Group 1) reached a MDT of 29.4℃ (for 2 days) and experienced temperatures >26.0℃ (previous highest MDT) for over 30 days between Dec'10-May'11. With an increasing trend in temperatures and a low bleaching temperature threshold, the prevalence of bleaching events at the Abrolhos could be on the increase, which has important implications for management of this unique high latitude coral reef system.

9A Coral bleaching & climate change
Tuesday 10 July, 1530, Plenary Hall 2

Comparison of the photosynthetic bleaching response of four GBR corals

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During an experiment designed to capture the proteomic response of corals undergoing stress-mediated bleaching, we characterised the photosynthetic performance of their symbionts in hospite. Fragments of four coral species, *Acropora microphthalma, Acropora formosa, Stylophora pistillata* and *Pocillopora damicornis* were collected from 10-15m depth (Davies Reef, central GBR) and exposed to natural and shaded light under temperature-controlled conditions for 48h at a depth of 40cm in a shipboard, light-exposed tank. After 2 days of stress (high light/low temperature, high light/high temperature, and low light/high temperature), the Acroporids were severely bleached whereas the *Stylophora* and *Pocillopora* fragments had retained some pigmentation. Light adapted PSII Yield values declined to 0.1-0.2 units at midday in all coral species but increased during the afternoon. From these 2 day experiments, the rate of PSII Yield recovery (Yr), calculated as the increment in light adapted PSII-Yield recovered from midday to dusk, was compared. Results show that *A. formosa* is a thermally-sensitive species with reduced Yr values under both light conditions. *A. microphtalma* and *S. pistillata* were thermally-tolerant but light-sensitive with enhanced Yr values under low light decreased values under high light treatment. *Pocillopora* was the least sensitive to bleaching and showed attributes of light and thermal tolerance with up to six times higher Yr values than the other species. We have been successful in culturing symbionts from representatives of these species, which allows us now to compare the photophysiological properties of these symbionts ex hospite. Such comparisons will be discussed in context with our experimental observations.

9A Coral bleaching & climate change
Tuesday 10 July, 1015, Plenary Hall 2

Latitudinal distribution of algal symbionts (*Symbiodinium* spp.) in corals of Madagascar

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The island continent of Madagascar spans nearly 13.5° of latitude in the SW Indian Ocean, characterized by well-developed coral reefs and provides an ideal study site to examine the latitudinal distribution of scleractinean algal symbionts (*Symbiodinium* spp.). *Symbiodinium* distributions at 4 different sites between 2001 and 2009 were investigated using Denaturing Gradient Gel Electrophoresis (DGGE) to analyze the internal transcribed spacer-2 (ITS-2) region of *Symbiodinium* ribosomal DNA. Cladal symbiont compositions of reef corals were different between sites, with corals at northern sites containing a higher relative frequency of clade D *Symbiodinium* (occurring as mixed clade C+D communities). Nominal logistic analyses found a significant effect of coral taxa and site, and different congeners of subcladal dominant ITS-2 types were found at different latitudes. Within the genus Acropora, *Symbiodinium* C3 (specifically subtype C3z) was found predominantly in the north, while C1 dominated acroporid corals in southern sites. Increases in mixed *Symbiodinium* C+D assemblages occurred at southern sites that had experienced temperature stress during the intervening sampling period, while the less thermally stressed north experienced decreases in mixed *Symbiodinium* communities. Sea surface metrics and *Symbiodinium* richness between different sites and time intervals were not found to be significant in determining symbiont distributions. Latitudinal gradients in *Symbiodinium* may provide important insight into how coral species can adapt or acclimatize to changing environmental conditions through shifts in symbiont community composition. This will help improve our understanding of how projected climate change in the SW Indian Ocean will affect survival trajectories for coral reefs in the region.

9A Coral bleaching & climate change
Wednesday 11 July, 1445, Plenary Hall 2

Causes of differential coral bleaching in space and time

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Many factors affect the bleaching response of a coral colony when exposed to increased temperature and light. The intensity and rate of exposure to bleaching conditions are foremost; however, other factors can either enhance or

reduce the effects of the physical environment. Such factors can be grouped into three categories: physical (e.g. currents), ecological (e.g. species assemblages), and biological (e.g. symbiont clades). The causes of differential coral bleaching can be assigned relative importance dependent upon the spatial scale observed (e.g. within a coral reef or intracolonial). Within and among these categories there are variations upon the relative importance of a given factor. For instance, does coral morphology or the age of a colony have more of an effect on the bleaching response, or do these factors matter when the location experiences doldrums or increased rainfall? Or, do other factors such as repeated exposure or local adaptations (e.g. tropical or subtropical) have more of an impact? Patterns present in factors which increase susceptibility and resistance will be highlighted, which will aid in the prediction of recovery or mortality of corals during a bleaching event. Coral reef management decisions can become more informed for bleaching events, should the decision be to protect susceptible or resistant areas.

9A Coral bleaching & climate change
Wednesday 11 July, 1645, Plenary Hall 2

Successive coral bleaching events on the world's southernmost coral reef

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The world's southernmost coral reef occurs at Lord Howe Island (LHI) (31°33'S, 159°05'E), with more than 80 scleractinian species occupying the reef benthos. During the 2010 austral summer, higher than normal sea surface temperatures (SST), coincident calm seas and low cloud cover resulted in an extensive coral bleaching event at LHI. Seawater temperatures again exceeded thermal bleaching thresholds during summer 2011, contributing to a successive coral bleaching episode. Repeated coral bleaching assessments (comprising replicate belt and video transects) were completed at 5 lagoon and 2 reef slope sites between March 2010-2011. Coral bleaching response was categorised according to pigmentation characteristics. Over 90% of coral colonies were moderately or severely bleached at 2 sites in the lagoon in March 2010. Differential bleaching susceptibility of corals was variable both within and between families, with pocilloporid and poritid corals showing the greatest level of susceptibility. Bleaching-related coral mortality was apparent in March 2010, with up to 25% of corals at one lagoon site having partial or complete bleaching-induced mortality. Although partial mortality of affected colonies increased between March-September 2010 at all lagoon sites, some pigmentation recovery was evident within the coral community. However, the proportion of moderately bleached coral colonies increased in March 2011 as a consequence of the successive thermal anomaly. These results demonstrate that high latitude coral reef assemblages are susceptible to bleaching stressors. Repeated bleaching stress is likely to compromise the recovery of coral assemblages at LHI, particularly given their geographic and genetic isolation from other reefs.

9A Coral bleaching & climate change
Wednesday 11 July, 1515, Plenary Hall 2

Remote sensing and in situ investigation of coral bleaching around Zhongjian Island

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Coral bleaching is the primary cause of mass coral mortality and reef degradation throughout the world. A coral bleaching alert was detected by NOAA coral reef watching system in Sept 2011 at the Zhongjian Island, Xisha Islands (XS), in the northern South China Sea (SCS). Ecological surveys and measurement of coral zooxanthellae density and sea surface temperatures (SST) was used to study the coral bleaching in this area. Bleached corals accounted for 20% of total corals in the investigated quadrats. Based on measurements of SST and the satellite Hotspots and DHW data (NOAA), Coral Reef Watch system alarmed that the extremely high SSTs would trigger coral bleaching event in the sea area around Zhongjian Island (Alert level 1). Our results suggest that most corals were experiencing the early stage of bleaching, and many of them (>60%) were experiencing the recovery from bleaching. The temperature thresholds used to predict coral bleaching based on satellite data by NOAA coral reef watch system are likely to underestimate the extent and intensity of coral bleaching, at least in the XS. More accurate predictions of coral bleaching on a local scale need a more detailed monitoring system in the Zhongjian and Xisha Islands.

9A Coral bleaching & climate change
P090

Dynamics of mixed *Symbiodinium* communities in corals recovering from bleaching

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The recovery of *Symbiodinium* communities after bleaching is critical for a coral's immediate survival and may also play an important role in their resilience to climate change by providing an opportunity for symbiont community shifts. Symbiont recovery dynamics may be influenced by host regulatory control, external environmental conditions, or the diversity and abundance of symbiont types remaining in bleached tissues, which depends on how severely a coral has

bleached. To investigate these effects on the recovery process, we monitored the structure and function of *Symbiodinium* communities in fragments of *Montastraea faveolata* (n=161) for 3 months as they recovered from low, medium, or high severity bleaching treatments (7, 10, and 14 days at 32°C) at either 24 or 29°C. The maximum quantum yield of photosystem II (Fv/Fm) in symbiont communities was measured biweekly, and DNA samples were taken monthly for quantification of symbiont community structure using real-time PCR. Recovery of Fv/Fm was fastest in corals that 1) bleached less severely, 2) recovered at 29°C, and 3) hosted higher initial proportions of clade D *Symbiodinium*. The trajectories of abundance of *Symbiodinium* clades A, B, C, and D during recovery serve to elucidate the influence of remnant symbionts and the environment on recovering community composition, and the conditions under which community shifts may occur following bleaching. These results have major implications for understanding the ability of corals to acclimatize to a changing environment and resist future stress events.

9A Coral bleaching & climate change
Wednesday 11 July, 1500, Plenary Hall 2

An applied high latitude eastern Australian coral bleaching model

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The bleaching susceptibility of scleractinian corals that dominate high-latitude reefs along the Australian eastern seaboard is unknown. We monitored coral health at the Solitary Islands Marine Park (SIMP) and Lord Howe Island Marine Park (LHIMP) between 2005 and 2007 in order to: 1) determine spatial patterns of coral bleaching response and variability of bleaching susceptibility among coral taxa; and 2) predict coral bleaching thresholds at 30°S and 31.5°S, extrapolated from published bleaching thresholds. Using these biological and physical data we hypothesized a subtropical New South Wales (NSW) coral-bleaching model. During the survey period minor bleaching was observed in dominant coral families including Pocilloporidae, Poritidae and Dendrophylliidae in the SIMP and Pocilloporidae, Poritidae and Acroporidae (*Isopora* and *Montipora* spp.) in the LHIMP, with a clear difference in bleaching susceptibility found between sites and locations. Patterns of family bleaching susceptibility within the SIMP and LHIMP differed to those previously reported for the Great Barrier Reef. An analysis of published bleaching threshold estimates from tropical locations indicated that the bleaching threshold of the hard coral assemblage at northern NSW ranges between 26.5-26.8°C. This predicted threshold was confirmed by an extensive coral bleaching event on the world's southernmost coral reef at Lord Howe Island, during 2010. These results imply that dominant coral taxa at high-latitude eastern Australian reefs are highly susceptible to thermal stress. If rising seawater temperatures lead to more frequent coral bleaching events in future, a decline in total live coral cover at these locations is predicted.

9A Coral bleaching & climate change
Wednesday 11 July, 1145, Plenary Hall 2

Identifying patterns of coral bleaching using CoralWatch data

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Few datasets are available which examine global patterns of coral bleaching. Since 2003, CoralWatch volunteers have collected data across more than 60 countries, using the Coral Health Chart. This measure quantifies changes in colour associated with bleaching. We aimed to validate the capacity of the CoralWatch database to predict bleaching events, and examine patterns of bleaching frequency and seasonal colour variation. CoralWatch volunteers record the lightest and darkest colour of individual corals, on a 6-point scale representing density of symbiotic algae. The optimal metric for predicting bleaching events has not yet been identified. To determine this, we conducted an iterative series of logistic regressions examining two well-described bleaching events: (i) Thailand 2010 (data-rich example) and (ii) Caribbean 2005 (data-sparse example). Predictive metrics assessed were: raw scores (lightest-, darkest-, and mean-colour), and incremental dichotomised cut-offs (e.g. lightest colour 1, 2, etc). Models were run unadjusted, and adjusted for temperature, season and survey size. Across all models, the strongest predictor was 'mean colour2', which predicted events in Thailand ($p<0.001$; ORadj = 4.48; 95%CI = 2.92-6.87) and the Caribbean ($p<0.001$; ORadj = 3.64; 95%CI = 2.10-6.30). Compared to 2007-2009, the 2010 event yielded a higher proportion of corals within this threshold in May (23.1% vs 6.3%; $p<0.001$), June (37.7% vs 1.3%; $p<0.001$) and July (27.2% vs 5.5%; $p<0.01$). Analysis of spatial patterns of bleaching frequency and seasonal variation in coral colour will also be presented. Volunteer data effectively discriminates bleaching from non-bleaching events, highlighting the utility of the CoralWatch database for monitoring and research.

9A Coral bleaching & climate change
Wednesday 11 July, 1030, Plenary Hall 2

Analysis of coral tolerance to the effects of climate change

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Multiple variables are now linked to coral bleaching thresholds. For instance, corals from the genus Acropora in the Indo-Pacific are found to be less

vulnerable than Caribbean populations, which have suffered dramatic reductions in population size (97% range wide) and are listed as 'threatened' under the U.S. Endangered Species Act. Similarly, the threshold of corals to other effects of climate change, including ocean acidification, varies globally. For example, corals in the Caribbean are more resilient to the effects of ocean acidification than those on the Great Barrier Reef. Identifying the variables that determine tolerance to the effects of ocean acidification will allow managers to implement appropriate mitigation strategies. This study examines the literature for case studies on the effects of ocean acidification on corals to determine whether there are differences in the threshold tolerance of species in major tropical reef system regions (Caribbean, Australia, Hawai'i and Coral Triangle) and evaluates the mitigation plans for these effects.

9A Coral bleaching & climate change
P091

Massive bleaching of coral reefs induced by ENSO 2010, Puerto Cabello, Venezuela

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El Nino Southern Oscillation (ENSO) has generated global coral mass bleaching. We evaluated the bleaching of reefs at Puerto Cabello, Venezuela at 5 localities at 2 depths: 3 and 5 meters. The coral cover and densities of colonies were estimated in 15 quadrats of 1 m^2 at each depth. Living coral cover and the number and diameter of bleached and non-bleached colonies of each coral species were recorded. The colonies were classified according to the proportion of bleached area. Satellite images Modis Scar (1km x 1km spatial resolution) were analyzed for chlorophyll-a concentration and temperature in August, September, October and November in 2008, 2009 and 2010. Precipitation, wind intensity and air temperature data were evaluated. 58.3% of colonies, belonging to 11 hexacoral species, were affected with the greatest responses in *Colpophyllia natans*, *Montastraea annularis* and *Montastraea faveolata*. The salinity in situ varied between 30 and 33 ppm and high levels of turbidity were observed. According to the satellite images, in 2010 the surface water temperature reached 31ºC in August, September and October, which was higher than in 2008 and 2009. Regionally chlorophyll values were higher in 2010 than in 2008 and 2009. The meteorological data indicated that precipitation in November 2010 was three times higher than in November 2009. Massive coral bleaching occurred during a 3 month period of high temperatures followed by 1 month of intense ENSO-associated precipitation.

9A Coral bleaching & climate change
Tuesday 10 July, 1630, Plenary Hall 2

2010: mass bleaching of corals in Aceh, Indonesia

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Aceh is one of the provinces which have the largest coastal region in Sumatera Island, Indonesia. Aceh is rich in both biological and non-biological marine resources. In addition, 25% of total Acehnese are dependent on the coastal ecosystems mainly from the fisheries sector. While, the reefs of Aceh have proved resistant to the Indian Ocean Tsunami, coral bleaching as an effect of climate change occured in surrounding Aceh water during 2010. Coral bleaching was first observed at Pulau Weh, Aceh, Indonesia (6°08'S, 106°45'E) on 12 May 2010. This is the first time that mass bleaching of corals has been observed on Pulau Weh, Aceh. The bleaching index at 13 sites surveyed in late May 2010 ranged from 41 to 70.22. The highest bleaching index was found at Gapang (70.23) and the lowest bleaching index was found at Reteuk (41.16). Mass bleaching on these previously unaffected reefs highlights how difficult it is to climate proof reefs. We conclude that urgent global action on CO_2 emissions is essential for the long term preservation of reef ecosystems.

9A Coral bleaching & climate change
Tuesday 10 July, 1715, Plenary Hall 2

Bleaching of the fire corals *Millepora*

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Fire corals *Millepora complanata* and *M. alcycornis* are known to 'bleach' readily in the Caribbean. The following factors were investigated: 1) they are Hydroids, containing a very porous skeleton with tissues that extend throughout; 2) many of the branches stand vertical, receiving far less light than horizontal surfaces. While *Millepora* is a hydroid, it follows a similar pattern to scleractinian coral bleaching: a) symbiont densities decrease with release-rates dependent on temperature and light; b) hydocorals taken from 60 m deep show an increased loss of zooxanthellae/pigments when heat stressed compared to shallow water specimens; c) the gross photosynthesis: respiration ratio decreases with an increase in temperature for the hydocoral: d) the Q_{10} of the hydrocoral increases with temperatures at 32°C compared to <30°C. Growth rates of symbionts exposed to bleaching temperatures slow or stop in hydrocorals, implying they are impaired or dead. The porous

skeleton is thought to provide some protection from direct light impinging on the symbionts, which may increase the diversity of different subcladal groups living within the hydrocoral. Millepora contains *Symbiodinium* subcladal types A3, A4 and B1, however it is not common for more than one type to be found in a colony. Changes in heat-stressed zooxanthellae in *Millepora* are slower than in other corals at the same temperature, possibly due to the protection by the skeleton or the different types of *Symbiodinium*.

9A Coral bleaching & climate change
P092

Incresaed number of mucocytes in *Aiptasia pallida* following heat-induced bleaching

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While much research has emphasized the numerous and critical roles of mucus production in coral, only a few have focused on its dynamics following bleaching events. Here, we examine the response of the sea anemone *Aiptasia pallida* to a transient elevation of water temperature combined with high illumination. Following 30h of exposure to stress conditions (33°C and 1900 µE m^{-2} s^{-1}), anemones showed a significant reduction of their zooxanthellae concentration followed by a progressive recovery over 8 weeks. Histological analyses revealed an increase in cell proliferation in both ectoderm and gastroderm 1 day following the stress. This increased proliferation seemed to be sustained for 3 weeks before returning to control values 8 weeks after stress. Moreover, the number of mucocytes progressively increased in the ectoderm over 3 weeks and returned to a normal level at 8 weeks after the bleaching event. These results suggest that a bleaching event is able to induce an increase of cell proliferation in both gastroderm and ectoderm of cnidarians. While the new cells formed in the gastroderm would most likely be host to new zooxanthellae, the fate of new cells in the ectoderm is still not completely unraveled. Those new cells seem to be, in part, contributing to the increased number of mucocytes which could eventually help shifting to a temporary heterotrophic state until restoration of the symbiosis.

9A Coral bleaching & climate change
P093

Microscopical investigations reveal autophagy-related bleaching in *Aiptasia pallida*

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Coral bleaching functions as a stress response to elevated temperature and/or light conditions resulting in the loss of intracellular dinoflagellates (*Symbiodinium*) from host gastrodermal tissues. This process involves a complex series of cellular events that occur throughout the duration of the bleaching episode. However, few studies have investigated the early host stress response when symbiotic breakdown is initiated. In this study, multiple microscopical techniques, including extensive 1) transmission electron microscopy and 2) fluorescence microscopy were utilized to characterize the series of cellular events that occur at various stages during the first 48 hours of stress. Bleaching was induced by exposing both symbiotic and aposymbiotic anemones, *Aiptasia pallida*, to heat-light stress conditions of ~32.5°C at 140 µmols irradiance for 12 hours daily. Detailed ultrastructural examinations revealed a significant increase in autophagic structures and cellular degradation within the first 48 hours of stress treatment and after treatment with the autophagy inducer, rapamycin. Additionally, bleaching occurred when numerous symbionts detached from the apical end of highly degraded autophagic cells in an apocrine-like manner. This study provides the first ultrastructural evidence of host autophagic degradation during heat-light stress in a cnidarian system and also supports earlier suggestions that autophagy is an active cellular mechanism during early stages of bleaching. Similar microscopical approaches should be employed in future molecular, ecological, and physiological investigations in order to gain a better understanding of the cellular processes that underlie coral health.

9A Coral bleaching & climate change
Wednesday 11 July, 1700, Plenary Hall 2

Historical thermal regimes define limits to acclimatisation in reef corals

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Acclimatisation of corals to temperatures exceeding historical thermal regimes was investigated by reciprocal transplantation of *Acropora millepora* colony halves between the warm Central and cool Southern regions of the Great Barrier Reef (GBR). Coral partnerships with *Symbiodinium* D from the Central GBR experienced gradually cooling temperatures (~0.35°C/week) and partnerships with *Symbiodinium* C2 from the Southern GBR experienced gradually warming temperatures (~0.6°C/week). In both locations, native colonies remained healthy for the duration of the study and transplanted colonies were visibly healthy over initial months when temperatures remained within native thermal regimes. However, during winter, all colonies transplanted from the Central to Southern

GBR bleached and the majority suffered whole (40%) or partial (50%) colony mortality when they experienced temperatures <1°C below the 15-year native minimum. Similarly, during summer, all colonies transplanted from the Southern to Central GBR bleached and suffered whole colony mortality when temperatures rose 1-2°C above the 15-year native maximum. During summer bleaching, *Symbiodinium* changed within transplanted colonies from type C2 to D, but photochemical monitoring did not detect any associated gain in thermal tolerance. Furthermore, growth rates in transplanted corals were less than half of native corals at both locations. At the Southern GBR, this can be attributed to winter bleaching and mortality in transplants, but at the Central GBR reduced growth was measured before transplants showed any visual signs of stress. All investigated parameters demonstrated a strong interaction between genotype and environment indicating that thermal limits of *A. millepora* are primarily defined by genetic adaptation.

9A Coral bleaching & climate change
Monday 9 July, 1645, Plenary Hall 2

Changes in biochemistry of the coral symbiosis by vibrational spectroscopy

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The coral symbiosis is highly sensitive to environmental factors with temperatures as small as 1-2°C above summer averages leading to coral bleaching events where zooxanthellae, photosynthetic microalgae, are expelled from the host. These events are occurring more frequently, over a more widespread area and are becoming more intense due to the elevation of ocean temperatures in response to climate change. Other factors causing stress to the symbiosis are changes in pH, salinity and light intensity. Of particular interest is the biochemistry of the coral symbiosis. Zooxanthellae are responsible for providing the host tissue with a large supply of organic carbon and in turn, the host absorbs inorganic nutrients from the surrounding ocean, or from heterotrophic feeding on zooplankton. Environmental stress can have an effect on the biochemical energy balance between the host and the symbiont. Advances in analytical chemistry have enabled the study of complex biological systems. Vibrational spectroscopy techniques such as Raman and FTIR spectroscopies can provide detailed structural information and detect changes in biochemistry including lipids, carbohydrates and proteins.

9A Coral bleaching & climate change
P094

Spatial variability of coral bleaching in Palau during a regional thermal stress event in 2010

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While thermal stress continues to emerge as a global concern for coral reefs, few studies have examined the spatial variability of bleaching responses during thermal stress events. We examined the spatial extent and severity of bleaching in Palau during a regional thermal stress event in 2010. Our objective was to determine whether there were any spatial differences in thermal stress that were habitat or taxa dependent. We found that coral bleaching was significantly higher on outer and patch reefs than in the bays, and was particularly severe in the northwestern lagoon. While the reefs in the bays may provide a safe haven for some coral species through climate change, these reefs, alone, are not resilient because they are more vulnerable to land-use change than patch and outer reefs. Therefore, protecting nearshore reefs from local disturbances may help buffer the coral reefs of Palau against climate-change induced disturbances.

9A Coral bleaching & climate change
Monday 9 July, 1730, Plenary Hall 2

Coral bleaching and the robustness trade-offs

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The success of scleractinian corals as reef-builders during the last 200 million years in the shallow, oligotrophic waters of the tropical oceans is the result of the establishment of mutualistic symbioses with autotrophic microalgae. In these nutrient-poor environments, the efficiency by which different primary producers collect and utilize solar radiation plays a key role structuring communities. Multiple scattering of solar radiation by coral skeletons, allow these organisms to be the most efficient solar collectors in nature. The nutritional advantages emerging from their symbiotic condition allow corals, under most circumstances, to successfully outcompete other benthic primary producers, while depositing large quantities of calcium carbonate, therefore playing a key role in the formation and maintenance of the reef structure itself. The evolution of this efficient solar collection mechanism probably increases the fragility of corals to environmental perturbations. In this context, and despite the success of reef corals since the Triassic, these organisms appear to be extremely

fragile when exposed to rapid environmental changes. For example, small increases in SST, such as those already attributed to global climate change, can trigger a complex cascade of cellular and molecular events that eventually results in the collapse of the symbiotic associations in a phenomenon know as coral bleaching. Here we provide a theoretical framework aimed to explain how the high efficiency achieved by symbiotic corals in terms of light collection and utilization constrain the robustness of the holosymbiont under environmental change.

9A Coral bleaching & climate change
Wednesday 11 July, 1715, Plenary Hall 2

Evidence of local thermal adaptation in a Caribbean coral

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The long-term persistence of coral reefs under global climate change scenarios depends largely on the ability of corals to track increasing temperatures with evolutionary adaptation. The presence of conspecific corals across broad latitudinal gradients suggests that local adaptation does occur. However, the patterns and mechanisms enabling coral adaptation to varying thermal environments remain poorly understood, particularly in the Caribbean. In the Florida Keys, nearshore corals are exposed to temperature extremes in both the summer and winter, while offshore corals experience a less variable thermal environment. We hypothesized that these spatial differences in temperature result in local thermal adaptation, with inshore corals exhibiting greater resilience to thermal stress than offshore corals. We conducted both common garden and reciprocal transplant experiments using colonies of *Porites astreoides* collected from inshore and offshore reefs in the Florida Keys. Growth, bleaching and algal symbiont photosystem function were quantified as proxies of fitness. To identify underlying molecular pathways affected by long-term thermal stress, we employed an RNA-seq methodology to evaluate global gene expression patterns in the host. In the common garden experiment, we found significant genotype by environment (GxE) interactions for symbiont related traits, suggesting that inshore corals are locally adapted to sustained temperature stress. We predict that the reciprocal transplant data will also demonstrate significant GxE interactions indicative of local adaptation. Ongoing analysis of genotype data for both hosts and symbionts will provide insight into the relative roles of genetic and physiological mechanisms potentially driving local thermal adaptation in this system.

9A Coral bleaching & climate change
Wednesday 11 July, 1430, Plenary Hall 2

Coral bleaching in Ratatotok Peninsula, Indonesia: 15 years monitoring data

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Ratatotok Peninsula and its surrounding areas are integrated to South-East Minahasa District of North Sulawesi Province, Indonesia. 15 years of hard coral and sea surface temperature data were collected respectively. In 1997, 2000 and 2010 the surface temperature was noted to rise about 2-3 degree of Celsius. The total coverage of hard corals declined or trended to decline during those years. Although several other causes (i.e. bombing, poisoning, netting and *Acanthaster plancii* predation) were also possible reasons for coral decline, bleaching events that occurred in 1997, 2000 and in 2010 could be blamed as major factors that have ruined the reefs in these areas. Nevertheless, not all hard corals were affected. Compared to other Indonesian reefs which were also affected by coral bleaching, most of coral genera affected in this study area were the dominant genera, such as *Acropora* (at Ratatotok Peninsula and Hogow Island) and Galaxea (at Ratatotok Peninsula). It was discovered that bleaching events in those years corresponded to increasing sea temperature (CTD data logger). However, after several months, it seemed that almost all coral which suffered bleaching survived. This survival was most likely due to strong currents.

9A Coral bleaching & climate change
Tuesday 10 July, 1700, Plenary Hall 2

Do clouds save the Great Barrier Reef?

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Evidence of global climate change and rising sea surface temperatures (SSTs) is now well documented in the scientific literature. However, climate modelers have not yet been able to capture the full complexity of the physical processes surrounding climate change, largely due to the uncertainties regarding cloud feedback mechanisms. This has limited the quality of climate change predictions, notably at the local scale, and has led to the assumption of dire environmental conditions for coral reefs around the world. Here,

we look for evidence of cloud feedback mechanisms, which may limit predicted rises in SSTs. To do this we explore patterns of cloud cover over a cross-section of the Great Barrier Reef in both El Nino and La Nina years using daily satellite imagery, ground-truthed with in situ measurements of Photosynthetically Active Radiation (PAR). Our results indicate that extensive low cloud cover reduces incoming solar radiation, which is in turn responsible for limiting SST and consequent thermal stress on corals. While other physical processes are significantly involved in limiting SSTs as part of well-established feedback cycles (e.g. wind evaporation), we find that build-up of low cloud cover due to thermal anomalies is a key process in constraining SSTs. Our work supports recent suggestions that an ocean thermostat involving cloud feedback mechanisms among others may prevent SSTs in the tropics from rising much beyond their current range, with direct implications for the future of coral reefs.

9A Coral bleaching & climate change
Tuesday 10 July, 1030, Plenary Hall 2

The changing thermal environment for tropical coral reefs

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Recent mass coral bleaching events are a clear indication of potential future impacts on tropical coral reefs of a rapidly warming world. These events have occurred with the relatively modest amount of surface ocean warming observed to date compared with what is projected for the future. Analyses of sea surface temperatures (SSTs) variations of the tropical oceans (30°N-30°S), between 1981-2010 and 1951-1980, shows considerable spatial variability. Significant warming, between the two 30-year periods, occurred in 63% of the tropical oceans, <1% significantly cooled and 36% showed no significant change. Greatest absolute warming has occurred in regions of largest inter-annual SST variability but, when standardized by the inter-annual variability, greatest relative warming has occurred in the near-equatorial Indo-Pacific region and, to a lesser extent, in the equatorial Atlantic. Analyses of the distribution of tropical SSTs (in 1°C classes from <17°C to >32°C) between these two periods also highlights these near-equatorial regions as areas of greatest observed changes, both losses and gains of given SST classes. Thus, although higher latitudes have and will experience greatest absolute warming of the surface oceans, these near-equatorial regions, where tropical marine organisms exist within a much narrower temperature range, are experiencing the greatest relative changes in their thermal environment.

9A Coral bleaching & climate change
Monday 9 July, 1630, Plenary Hall 2

Thermal stress physiology and mortality responses in scleractinian corals of Mauritius

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Photo-physiological and climate change related bleaching were studied in eight selected species of scleractinian corals, namely *Acropora cytherea, Acropora hyacynthus, Acropora muricata, Acropora* sp., *Pocillopora damicornis, Pocillopora eydouxi, Galaxea fascicularis* and *Fungia* sp. from October 2008 to December 2009 around Mauritius. PSII functioning were measured in partially bleached (PB), pale (P), bleached (B) and non-bleached (NB) corals using a pulse-amplitude-modulated (PAM) fluorometer. Temperature records from January till March 2009 showed that the surface seawater temperature was at least 30°C. The recorded physical parameters in May 2009 indicated a temperature, dissolved oxygen, salinity, and pH of 27.52 ± 0.33°C, 20.38 ± 0.77 mg L^{-1}, 33.5 ± 1.45 o/oo, and 7.10 ± 0.15, respectively. PSII functioning (Fv/Fm) was lower in PB, P and B samples as compared to the NB ones in *A. cytherea* and *A. hyacynthus*. In *A. muricata* PB and B were lower than the NB Fv/Fm, except for the P ones. Pale colonies of *P. damicornis* and *G. fascicularis* did not differ from their non-bleached ones. Fv/Fm measured in *P. eydouxi* and *Fungia* sp. was normal and no recorded bleaching occurred. Tabular corals, *A. cytherea* and *A. hyacynthus*, showed the highest levels of recent mortalities while *A. mucricata* exhibited high levels of partial colony mortalities and *P. damicornis*, *P. eydouxi*, *G. fascicularis* and *Fungia* sp. did not show any signs of mortality. *A. cytherea* and *A. hyacynthus* were thermally most vulnerable while *P. damicornis*, *P. eydouxi*, *G. fascicularis* and *Fungia* sp. were the most tolerant coral species.

9A Coral bleaching & climate change
Wednesday 11 July, 0930, Plenary Hall 2

What two coral can bleaching events tell us about resilience

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Coral bleaching occurred in 2005 and 2010 in the US Virgin Islands providing the opportunity to compare coral responses at long-term study sites (depths 19 m to 3.6 m) during two different thermal stress events. In 2005, the in-situ mean daily temperature exceeded 29.5°C for 56 days (43 consecutive) leading to bleaching of >90% coral cover (>50% severely bleached) at 5 study sites

around St. John and Buck Island, St. Croix. Subsequent coral disease outbreaks caused extensive mortality with an average 61% decrease (range at 5 sites: 53%-79%) in coral cover over 2 years. In 2010, mean daily temperature exceeded 29.5℃ for 39 days (20 consecutive) and led to bleaching of >60% of coral cover (5.4% severely bleached), however no disease outbreak occurred and no significant loss of coral cover was detected. While the less-severe bleaching and lack of mortality may indicate reef resilience, data also shows the thermal stress which caused the two events varied substantially. In addition, the winters before each bleaching event had substantially different thermal patterns. Mean daily temperatures from January through March 2005 were within the 16 year historical ranges. During the same period in 2010, temperatures were warmer than the historical ranges. Long-term temperature data suggest bleaching events could become more common. Annual average temperatures show a significant warming trend ($p<0.001$) between 1998-2010, with no years with days above 29.5℃ between 1988-1997, and 9 years with days above between 1998-2010, including each of the past 6 years.

9A Coral bleaching & climate change
Tuesday 10 July, 1200, Plenary Hall 2

Status of coral reef health in the northern Red Sea, Egypt

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This study aimed to provide baseline knowledge of coral health and coral diseases prevalence at 9 reef sites in the northern Egyptian Red Sea: I (El-Ain Al-Sukhna), II (Ras Zafarana), III (Hurghada), IV, V & VI in Ras Mohammed (Marine Protected Area); IV (Ras Ghozlani), V (Old Quay), VI (Yolanda reef), VII (Ras Umm Sid, Sharm El-Sheikh), VIII (Wood house reef, Sharm El-Sheikh), and IX (canyon reef, Dahab). Diseases prevalence varied among the studied reef sites with site III having the highest prevalence of disease (46%), followed by site VII (44.4%), and site I (40%). On the other hand, site VIII (Wood House reef, Sharm El-Sheikh) had the lowest prevalence of disease (1.78%). Field surveys for coral diseases and signs of compromised health in the studied reefs revealed overall prevalence of 30.48%. Signs corresponding to 9 coral diseases and compromised health were detected; Black Band Disease (BBD) (13.03%), signs of compromised health (9.42%), White Syndrome (WS) (4%), Coral bleaching (2.2%), Pink Line Syndrome (PLS) (0.9%), Ulcerative White Spots (UWS)(0.53%), *Drupella cornus* snail predation (0.14%), fish predation (0.23%), and Skeletal Eroding Band (SEB) (0.03%). The higher prevalence of coral diseases were recorded in species *Favia stelligera* (6.1%), followed by *Porites lutea* (5.3%), and *Goniastrea edwardsi* (4.06%). The enhanced local anthropogenic stresses and increasing sea surface temperature due to global warming may be the potential factors responsible for the initiation and the persistence of some coral diseases in the studied reefs.

9A Coral bleaching & climate change
Tuesday 10 July, 1215, Plenary Hall 2

Multiple disturbances cause significant mortality of Ningaloo Reef corals

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Ningaloo Reef on the west coast of Australia is one of the world's largest fringing reef systems. Coral bleaching due to high temperatures has not been recorded at Ningaloo and it had previously been suggested the reef was resistant to bleaching events due to the cooling effects of the Ningaloo counter-current in the summer months. However, extended elevated temperatures of above 28℃ between December 2010 and March 2011 coincided with indiscriminate bleaching of hard and soft coral species causing ~90% mortality on the eastern side of the Ningaloo Marine Park. In addition to elevated water temperatures, corals were further exposed to damaging stress from 3 cyclones during the same period which left branching colonies fragmented and plates overturned. On the western side of Ningaloo, coral bleaching was less severe (5-15%) and more selective (predominantly affecting Pocilloporids), but further evidence of cyclonic disturbance was clear. The eastern tip of the Ningaloo Marine Park represents a unique area, where complex currents and eddies drive micro-scale sea temperature fluctuations on a daily basis. Remarkably, this is the first record of coral bleaching for Western Australia's vast mainland coastline, an area spanning over 12,000km.

9A Coral bleaching & climate change
P095

The presence of DMSP, DMS and acrylate in GBR corals

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Dimethylsulphoniopropriate (DMSP), a ubiquitous molecule in the marine environment, is primarily produced by micro and macro-algae with the most prolific producers being the coccolithophorids and the dinoflagellates. There is much interest in this molecule as it is the precursor to the volatile gas dimethylsulfide (DMS), which contributes

significantly to the global sulphur cycle and is known to generate cloud-condensation nuclei., The importance of DMSP, DMS and acrylate (a second catabolism product) to corals and coral reefs is only just becoming apparent. High concentrations of DMSP have been measured in corals from the Pacific, including the Great Barrier Reef, and are attributed to their dinoflagellate endosymbiont *Symbiodinium*. The highest concentrations of these compounds have in fact been recorded in corals belonging to the genus *Acropora*. It is speculated that these molecules play an antioxidant role in mitigating the high levels of reactive oxygen species produced during photosynthesis and are thought to aid in structuring coral-bacteria associations. With predictions of increased stress to reef systems as a direct result of climate change, it is important to determine the implications for DMSP, DMS and acrylate metabolism in corals. We present here the use of a novel quantitative nuclear magnetic resonance approach, applying the ERETIC pulse sequence, to quantify the levels of these compounds in a number of coral species as well as corals subjected to laboratory induced stressors.

9A Coral bleaching & climate change
Wednesday 11 July, 1215, Plenary Hall 2

Changing oceans favor resistant *Symbiodinium*, but ecological shifts too slow?

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As oceans warm, high-temperature bleaching threatens reef-building corals. By hosting more temperature resistant algal symbionts, some common reef corals may elevate their thermal tolerances. Because the environmental correlates of temperature-resistant symbionts remain unclear, judging a site's likelihood of supporting such symbionts, now or in the future, is difficult. Here we gather distribution data of symbiont types from 143 studies including 80 scleractinian coral genera across 202 global localities and analyze the resulting database of *Symbiodinium* communities for correlations to a wide range of environmental variables. On the scale of the Indo-Pacific basin, we show strong correlations between more thermally resistant *Symbiodinium* genotypes and a site's long-term temperature, but no strong trend with a site's bleaching history nor history of episodic heating events. We further predict potential shifts in environmental suitability of distinct *Symbiodinium* genotypes by building multiple linear regression models of environmental correlates to current *Symbiodinium* genotype distributions and applying climate projection models. These models of future Indo-Pacific climate predict that areas now unsuitable for these thermally resistant genotypes will rapidly shift to favor their dominance. However, many of these areas currently host no such thermally resistant genotypes, raising the concern that environmental change will sweep over areas faster than dispersal and population growth can add these *Symbiodinium* types to reefs.

9A Coral bleaching & climate change
Tuesday 10 July, 1145, Plenary Hall 2

Can thermally tolerant symbionts slow the decline of Caribbean reefs?

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Temperature induced coral bleaching is one of the main drivers of reef degradation worldwide. To date, over 16% of the world's coral reefs have been lost as a direct consequence of coral bleaching. Climate models predict that the frequency and intensity of mass bleaching events will increase significantly throughout the 21st century. It has been suggested that an increase in the relative abundance of thermal tolerant clade D symbionts in coral populations may reduce the impact of bleaching in Caribbean coral reefs. However, recent studies indicate that while corals with clade D symbionts are more tolerant to increased temperatures, they have a lower growth rate than the same coral host with homologues more typical clades. Here we use a spatially realistic model to explore under what conditions an increase in the relative abundance of tolerant symbionts would lead to a reduction in the predicted decline of Caribbean reefs. Preliminary results using parameters based in the published literature suggest that an increase in the relative abundance of tolerant symbionts is unlikely to prevent the ongoing degradation and projected collapse of most Caribbean reefs.

9A Coral bleaching & climate change
Wednesday 11 July, 1530, Plenary Hall 2

Colony color predicts stress tolerance in reef corals

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Coral Fluorescent Proteins (FPs) are responsible for the striking color diversity of reef-corals and are arguably involved in stress tolerance through photoprotective and/or antioxidant properties, yet direct evidence of FPs conferring stress tolerance is lacking. Many coral species have both highly- and weakly-fluorescent color variants suggesting potential for intraspecific variation in stress tolerance. We describe distinct differences in FP content and divergent stress responses between intraspecific color morphs of the common coral, *Acropora millepora* from the Great Barrier Reef. Green and red corals differed in their relative

abundance of three FPs determining their visual appearance and were tested for their susceptibility to thermal stress and limited light and food availability. During 2 weeks of experimental heat stress, highly-fluorescent green morphs had greater thermal tolerance than their weakly-fluorescent red counterparts, resulting in substantially less bleaching (66% compared with 100%) and greater rates of recovery (46% compared with 0%) after 4 weeks at ambient temperature. We further examined the energetic links between FP production and nutritional status in a starvation experiment where, after 3 months of experimental starvation, FP content declined in all color morphs and colonies were more susceptible to disease. Our findings indicate a potentially (energetically) high cost in producing/maintaining coral pigments and suggest that corals with greater investment in FP production are more likely to withstand environmental stress. Accordingly, color is a potentially useful indicator of the capacity of coral colonies and populations to tolerate future environmental changes.

9A Coral bleaching & climate change
Tuesday 10 July, 1730, Plenary Hall 2

Acclimate and adapt? How will corals respond to future climate change?

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A key facet of future health of coral reefs is the extent to which coral populations will physiologically acclimate or evolutionarily adapt to future environmental conditions. On Ofu Island in American Samoa, corals in shallow back reef pools are strongly resilient to simulated coral bleaching experiments compared to conspecifics from adjacent pools that do not naturally heat up as severely. We are investigating the mechanisms of this resilience through a series of genomic tests of coral reaction to heat stress, genome-wide surveys of genetic variation among individuals, and response of symbiont populations. By simultaneously examining physiological response, genetic differences and symbiont shifts of corals with known environmental histories, we hope to understand the capacity of corals to respond to environmental shifts. These data may help pinpoint other areas where highly resilient corals exist, may help us understand if many corals can increase their individual resilience, and provide for important tools for identification and protection of the world's strongest reef corals.

9A Coral bleaching & climate change
Monday 9 July, 1745, Plenary Hall 2

Autophagic pathway components play a role in cnidarian bleaching

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Coral bleaching, the collapse of the symbiosis between coral host and dinoflagellate symbiont, is thought to occur via several different mechanisms including host cell apoptosis, necrosis, and in situ degradation of symbionts. One mechanism that could cause in situ degradation is autophagy, a highly conserved process (present in yeast to humans) by which cells internally degrade cellular components. Cells form a membrane, or autophagosome, around target components that fuses with a lysosomes, resulting in degradation. Previous studies have shown evidence that pharmacological agents which can initiate autophagy induce bleaching in the model anemone *Aiptasia pallida*. We were interested in determining if there are conserved autophagic pathway components that function in cnidarian bleaching. Homologs to three autophagic pathway genes: ATG7, ATG8 and ATG12, where identified from *A. pallida* transcriptomic resources. Expression of these homologs was quantified using QPCR in anemones subjected to a range of temperature stresses over a series of exposure times. In addition, the ATG8 homolog, which encodes a component of the autophagosome, was the subject of further investigation. In immunofluorescence studies of heat-stressed *A. pallida*, an anti-ATG8 antibody localized tightly around dinoflagellates in gastrodermal cells. To explore the function of *A. pallida* ATG8, it was cloned into a GFP-tagged vector, expressed in mammalian cells and monitored for autophagosomal formation. These studies confirm a role for autophagy in in situ degradation of symbionts during cnidarian bleaching.

9A Coral bleaching & climate change
Wednesday 11 July, 1115, Plenary Hall 2

Cold water bleaching of *Pocillopora* in the Gulf of California

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Corals from the Gulf of California experience broad changes in environmental conditions over an annual period and develop under extreme conditions. These coral communities might be better adapted for survival in an environment modified by global climate change because they already live under stressful conditions. They could constitute areas of refuge and play an important role in the recovery of impacted reefs. In the last few years, coral reefs have had bleaching events caused by anomalous temperatures below of 21°C. A bleaching event by cold water occurred in March 2011, allowing an opportunity to evaluate the susceptibility to bleaching. Bleaching was recorded at 3 locations along the southwestern coast of the Gulf of California. At each site, bleaching was documented using a photo-transect method. Transects were 20m long and continuous photo quadrant frames of

1 m^2 were taken. A stratified random point count method was used to estimate bleaching susceptibility in coral species with CPCe 3.6 software. Coral colonies were distinguished and recorded according to visible signs of bleaching: healthy, minor to partially bleached (<50%), and major to completely bleached colonies (>50%). Most of the observed corals (73-85%) showed signs of bleaching to a minor or major degree. The southernmost locations were the least affected by cold water bleaching. Differences in bleaching susceptibility to cold water were observed in *Pocillopora* species: *P. damicornis* > *P. verrucosa* > *P. capitata* > *P. meandrina*. Tagged colonies from previous years with symbionts C and D were bleached in this event.

9A Coral bleaching & climate change
Tuesday 10 July, 1545, Plenary Hall 2

Comparing recruitment of *Pocillopora damicornis* affected by the bleaching event

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Coral bleaching, caused by high seawater temperature, occurred throughout the Gulf of Thailand in May to September 2010. This study compares recruitment of the brooding coral *Pocillopora damicornis* before, during and after the 2010 bleaching event, using settlement plate experiments, at Khrok and Sak Islands, in the inner Gulf of Thailand. Before the bleaching event, average coral recruitment was 4.9 ± 0.23 colonies/m^2 for Khrok Island and 6.8 ± 0.51 colonies/m^2 for Sak Island. In contrast, during the bleaching event, there were no coral recruits at Khrok Island and the average of coral recruitment at Sak Island was only 0.62 ± 0.02 colonies/m^2. The settlement plate experiments after the bleaching event (September 2010 to May 2011) showed higher recruitment rates compared with during the bleaching event, 0.69 ± 0.01 colonies/m^2 for Khrok Island and 1.23 ± 0.09 colonies/m^2 for Sak Island. Low density of adult colonies of *P. damicornis* in the inner Gulf of Thailand after the bleaching event can explain low coral recruitment. Therefore recovery to the former levels of abundance of *P. damicornis* at Khrok Island and Sak Island will depend on successful settlement of planulae which is likely to be low. To give this coral species the best chance to maintain their populations in the face of coral bleaching events, additional anthropogenic stressors must be mitigated.

9A Coral bleaching & climate change
P096

Increased cell proliferation in *Seriatopora hystrix* following heat-induced bleaching

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While molecular processes occurring during bleaching events are slowly being unravelled, the mechanisms involved in tissue recovery and cell proliferation of the coral host remain unknown. Here, we examined the response of *Seriatopora hystrix* to a transient increase in water temperature. Exposure to 32°C for 18h lead to a loss of *Symbiodinium* sp. followed by a progressive recovery of algae density over a 8 week period. Histological analyses revealed a drastic increase in cell proliferation 1 day following the stressful event in both the ectoderm and the gastroderm of bleached corals. This increase was maintained over a week. In addition, newly born ectodermal and gastrodermal cells continued to divide more rapidly in bleached corals. These results suggest that following a bleaching event, cell division increases to promote recovery of the damaged gastroderm and possibly to boost the production of ectodermal cells needed to support a shift to heterotrophy in bleached corals. Current studies are undertaken to determine the identity and the fate of these newly-born cells.

9A Coral bleaching & climate change
P097

Oxidative stress-related gene expression in juvenile *Acropora millepora* corals

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The endosymbiotic relationship between scleractinian corals and *Symbiodinium* spp underpins the biodiversity and productivity of coral reefs worldwide. The genetic and physiological characteristics of *Symbiodinium* have large effects on coral host physiology and thermal tolerance. Thermal stress and bleaching is predicted to increase under climate change. Therefore, associating with temperature tolerant *Symbiodinium* types may help corals cope with acute heat stress events and facilitate longer-term adaptation to warming oceans. Temperature and light stress results in the production of toxic reactive oxygen species (ROS) and lead to the malfunctioning of the endosymbiotic relationship. The degree to which the molecular responses to thermal and oxidative stress

vary among corals with different symbiont types is still not well understood. Here, we present the results of a two-week laboratory-based stress experiment designed to examine the rates and molecular responses to thermal stress in *Acropora millepora* juveniles with different *Symbiodinium* associations. We detected significant changes in symbiont associations with 55-71% of coral juveniles changing their symbiont type during a 12-month growth period in the wild. We also quantified the expression of 50 genes with a putative role in heat and oxidative stress in coral juveniles over time. We describe the response of coral gene expression to elevated temperature over time. We also discuss differences in response among corals associated with different symbiont types (C1, D and mixed) and between those that changed dominant type vs those that did not.

9A Coral bleaching & climate change
P098

Life on the edge: corals in mangroves and climate change

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Thirty species of scleractinian corals are growing on or near red mangrove prop roots in Virgin Islands Coral Reef National Monument, St. John, US Virgin Islands. Many of the larger, intact colonies were alive during the bleaching and disease outbreak in 2005/2006 that caused an average decline of 60% of the coral cover on St. John's reefs. Although seawater temperatures would have been higher in these shallow waters than on the reefs, these colonies proved to be resistant. Species-specific and intra-specific differences in response to thermal stress provide clues as to how reefs might respond to climate change. In 2010, water temperature exceeded 30°C for 85 days (maximum=31.6°C), and most of the corals in the mangroves bleached. However, two major reef-builders varied greatly in their response to thermal stress. Colonies of *Diploria labyrinthiformis* (n=198) and *Colpophyllia natans* (n=69), a species that declined significantly on the reefs in 2006 because of disease, were examined in November 2010 and 2-6 months later. None of the *C. natans* colonies bleached, but 63% of the *D. labyrinthiformis* colonies did with 82% recovering normal pigmentation by May 2011. Only 4% of the *D. labyrinthiformis* colonies died completely, and 11% showed partial mortality. No disease outbreak occurred. Water temperatures have been lower in 2011 (only 10 days higher than 30° C, maximum=30.5° C), and no bleaching has been observed.

9A Coral bleaching & climate change
Monday 9 July, 1700, Plenary Hall 2

Cold causes acute but heat causes enduring stress in corals

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The increases in intensity and frequency of both hot and cold extreme events associated with climate change contribute to coral reef decline by causing widespread coral bleaching and mortality. Here, we show that cold stress (-5°C) can cause acute but tolerable physiological responses in branching corals, while an equivalent magnitude heat stress (+5°C) is ultimately more deleterious. Initially, cold-treated *Acropora yongei* have greater declines in growth and increases in photosynthetic pressure and impairment than heat-treated corals. However, after a few weeks, cold-treated corals showed physiological stability and improvement, indicating acclimation and initiation of recovery. In contrast, heat stress did not initially harm photosynthesis, but after a delay, photosynthesis quickly declined and corals experienced severe bleaching and cessation of growth. This study indicates that repeated short-term cold events will be more damaging for corals than short-term warm events, while long-term elevated temperatures will be more deleterious for reefs than long-term depressed temperatures.

9A Coral bleaching & climate change
Tuesday 10 July, 0945, Plenary Hall 2

Post-bleaching *Symbiodinium* clade, not prior stress exposure, determines coral thermotolerance

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Corals that recover from bleaching events have been thought to be more resistant to future stress. It is not known, however, whether this is due to physiological acclimatization of the coral host (or its symbionts) or to changes in the composition of the symbiont communities. To differentiate these hypotheses, we used quantitative PCR and imaging Pulse Amplitude Modulation fluorometry to assess the composition, abundance, and photosynthetic efficiency of *Symbiodinium* in *Montastraea cavernosa* in a two-phase bleaching experiment. First, corals experienced a 10-day exposure to either high temperature (32°C) or herbicide (600 µg/L DCMU) at the control temperature (24°C). Both treatments produced bleached corals, but the DCMU-treated corals did not experience heat stress. Corals were then allowed to recover at either 24°C or 29°C for 3 months. Corals maintained at 29°C recovered pigmentation and photochemical efficiency faster than corals held at 24°C. All corals recovered with more *Symbiodinium* in clade D (which includes stress tolerant members), regardless of the bleaching stressor or recovery temperature. Corals were then heat-stressed again

by exposure to 32°C for 10 days. Corals that had previously bleached and had recovered with more clade D symbionts did not exhibit bleaching in this phase, in contrast to previously unbleached control corals that had continued to host their initial, predominately clade C *Symbiodinium* communities. This observed increase in heat tolerance was independent of the first bleaching stressor and the recovery temperature, indicating that changes in *Symbiodinium* community composition, rather than prior exposure to high temperature, accounted for the increase in thermotolerance.

9A Coral bleaching & climate change
Wednesday 11 July, 1415, Plenary Hall 2

Coral skeletal fractality modulates light-backscattering to symbionts and bleaching susceptibility

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Global climate change threatens coral reefs with increased frequency of bleaching episodes resulting in extensive coral mortality. However, reef-building corals show differences in bleaching tolerance with some losing most of their symbiotic algae while others remain largely unaffected. These differences seem mostly due to the presence of thermally tolerant symbionts, but other factors also play a significant role. Here we propose that differences in coral skeleton morphology at several length-scales from nanometers to centimeters affect the light environment of the symbiont algae through diffuse light-backscattering resulting in differences in bleaching response when corals undergo thermal stress. We measured coral skeletal morphology at length-scales spanning eight orders of magnitude in 60 Atlantic and Indo-Pacific species that differ in bleaching susceptibilities. Multivariate linear regression incorporating skeletal microstructure (nanometers-micrometers), corallite size and complexity (micrometers-millimeters), and colony growth form (centimeters-decimeters) was statistically significant in predicting bleaching susceptibility ($p<0.02$). Skeletal microstructure, which determines light-scattering, was consistent with a 'mass-fractal'. Fractal morphology may be responsible for the strong morphological plasticity associated with variability in light intensity and nutrient flow-rates, thus affecting coral physiology. Mapping different length-scales of coral morphology in combination with coral bleaching susceptibility onto coral phylogenies indicates that these characters are generally homoplasious. While corals may be under selection to maximize exposure of their symbionts to solar radiation while simultaneously minimizing photo-damage, they optimized these functions through different strategies that may not be equivalently efficient at balancing the trade-off between benefits (increased photosynthetic activity) and costs (potential bleaching) of light-amplification.

9A Coral bleaching & climate change
Tuesday 10 July, 1115, Plenary Hall 2

Bleaching in high-latitude, deeper water corals in Western Australia

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Coral bleaching is well documented on shallow, tropical reefs, however, there are few published records of coral bleaching from high latitude (>26°C), deeper water (>20 m) assemblages. High latitude, deeper water reefs are thought to be less exposed to thermal stress and might act as potential refuges from the adverse effects of global warming. Here, we present results of bleaching susceptibility and survivorship surveys from 4 deeper water (>20 m), high latitude reefs (32°C) located off Perth, Western Australia. The observations and surveys followed a summer of record high water temperatures, with water temperatures elevated up to 4°C higher than the long-term monthly average for 150 consecutive days and above average temperatures extended to at least 50 m. Traditional (diver and towed video) and novel (Autonomous Underwater Vehicle) survey techniques revealed coral bleaching at depths of up to 50 m, with some species bleaching rapidly (1-2 weeks) and remaining heavily bleached for several months. The propensity for bleaching in deep water, high latitude corals raises the question of whether these habitats do provide refuges from bleaching on tropical coral reefs.

9A Coral bleaching & climate change
Tuesday 10 July, 1645, Plenary Hall 2

Developing new perspectives on *Symbiodinium* photosynthesis and coral bleaching

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The coral reefs are of enormous ecological, economic, and aesthetic importance, hosting a substantial fraction of the total biodiversity in the oceans. Corals, which are dominant organisms of the reefs, can be defined by the strong association of the cnidarian (coral) animals and its intracellular algal symbionts (*Symbiodinium* spp.), which provide most of the corals' energy through photosynthesis. However, in many locations around the globe reef ecosystems are deteriorating. This deterioration is

manifest as the bleaching of large coral stands (loss of the alga and subsequent death of the animal), and is a consequence of changing environmental conditions associated with the burning of fossil fuels (e.g. rising temperatures and ocean acidification). In order to better understand the causes and mechanisms associated with coral bleaching, we are monitoring the impact of changing environmental conditions on free-living *Symbiodinium* cultures, *Symbiodinium*-cnidarian associations maintained in the laboratory and corals in their natural habitat. We are especially interested in how photosynthetic activity of the alga responds to elevated temperatures and have used both fluorescence and gas exchange techniques to monitor this activity. Fluorescence-based measurements based on PAM fluorometry, a commonly used system to study photosynthetic activity of the corals, is often difficult to interpret because of fluorescence quenching associated with dinoflagellates. Oxygen evolution measurements appear more reliable, but they may be more difficult to use in field studies. We discuss these issues and how elevated temperatures impact both oxygen evolution and photosynthetic electron flow in both the alga and the alga-cnidarian association.

9A Coral bleaching & climate change
Wednesday 11 July, 1130, Plenary Hall 2

Organic carbon fluxes in *Stylophora pistillata* during a thermal stress

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Heterotrophy, through predation on zooplankton, can sustain metabolism in some coral species during bleaching events. Feeding on pico- and nanoplankton, as well as uptake of dissolved organic matter, can also be two important sources of energy, but have been poorly assessed. We therefore measured pico- and nanoplankton grazing as well as dissolved free amino acids (DFAA) uptake by the symbiotic coral *Stylophora pistillata* exposed to a thermal and light stress inducing bleaching. The total organic carbon (TOC) flux was also measured to quantify bulk C loss or gain. Under control conditions (27°C and 200 µmol photons $m^{-2}s^{-1}$), autotrophic C acquisition covered 94% of the respiratory needs of non-bleached corals, while pico- and nanoplankton grazing contributed 11%. TOC flux rates were net negative, indicating substantial TOC uptake by the corals. After the stress (31°C and 300 µmol photons m^{-2} s^{-1}), the contribution of auto- and heterotrophic C to the respiratory demand of bleached corals decreased to 64% and 7%, respectively. This suggests that corals have lost both their auto- and heterotrophic capacities. No significant change occurred in the DFAA uptake rates. However, a significant change in the TOC flux direction was observed, that resulted in TOC net release. Our findings reveal that a thermal and light stress not only significantly decreases the auto- and heterotrophic supply of C in *S. pistillata*, but additionally increases the loss of organic C. Consequently, the energetic budget of bleached colonies is severely impacted, suggesting that *S. pistillata* may suffer from increased bleaching event occurrence.

9A Coral bleaching & climate change
Tuesday 10 July, 1000, Plenary Hall 2

Newly discovered coral endosymbiont *Chromera* is more thermotolerant than *Symbiodinium*

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A new algal species was isolated from the Caribbean coral *Agaricia agaricites*. Genetic analysis, using sequencing of the small subunit RNA, showed high similarity to *Chromera velia*, an alga recently isolated from a coral in Australia. *Chromera* forms a distinct phylum in the Alveolata, Chromerida, which is separate from the Dinoflagellata. We compared the sensitivity to increased temperature of cultures of *Chromera sp.* and the dinoflagellate *Symbiodinium* (type B7, isolated from the coral *Madracis mirabilis*, Curacao). Comparison of the photosynthetic activities showed that *Chromera sp.* was much more temperature tolerant than *Symbiodinium* (type B7). This was in agreement with a lower relative content of unsaturated fatty acids in *Chromera*, which is generally linked to less fluid membranes and higher temperature tolerance. At all tested temperatures (28, 30, 33, 35°C), *Chromera* had a higher growth rate than *Symbiodinium*. The experiments also showed that *Chromera* was sensitive to light conditions that were optimal for *Symbiodinium*. The effective quantum yield of *Chromera* largely dropped during the light period, while the potential yield (after dark incubation of 30 minutes) remained maximal, suggesting effective mechanisms of photoprotection. The two species differed in their pigment composition, e.g. *Chromera* is lacking the dinoflagellate-specific pigment peridinin. If *Chromera* indeed plays a role as endosymbiont in corals, the observed temperature tolerance of *Chromera* will be highly relevant. During periods of increased seawater temperature, *Chromera* would have a competitive advantage over *Symbiodinium*. This could cause a shift in the relative abundance of *Chromera* and *Symbiodinium* within a coral host.

9A Coral bleaching & climate change
Tuesday 10 July, 1130, Plenary Hall 2

Coral bleaching reversal in two Pacific *Acropora* species

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Coral bleaching is becoming an increasingly serious problem for reefs. This study investigates a scalable methodology to ameliorate coral bleaching by reducing peak reef temperatures during the bleaching season. On a small scale, reefs can be cooled using electrical or renewable cooling apparatus, enabling measurement of biological response. On a larger scale, commercial upwelling systems enable many megawatts of cooling even after commercial use, potentially providing a way to cool and protect large reef transects each summer. In American Samoa, a small-scale cooling apparatus has been constructed to cool local reef water by 1°C, directing the cooled water onto bleached *A. muricata* and *A. pulchra*. Test results over 18-24 hours of treatment indicate a complete return to non-bleached color intensity in bleached areas; using CoralWatch coral-health charts in digital color images, color intensity increased from 1 to 5 within 24 hours as documented with calibrated digital photographs. This rapid increase in color intensity corroborates the theory that thermal stress is a primary driver for bleaching in these back reefs and suggests many interesting avenues for future bleaching prevention research.

9A Coral bleaching & climate change
Wednesday 11 July, 1545, Plenary Hall 2

Bleaching in the Andaman Sea: potential mitigation mechanisms

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The Andaman Sea experienced extensive coral bleaching events in 1991, 1995 and 2003 but showed no significant mortality during these events. In 2010 an extremely severe bleaching event was monitored on several reefs along an offshore cross-shelf island gradient. During the peak temperature phase up to 100% of corals were bleached, although not all reefs were affected this badly. Even 10 months after the peak in temperature stress most of the reefs still appeared stressed with slow recovery, although some reefs recovered faster. An unusual feature of the region is the existence of large amplitude internal waves (solitons) approaching the islands from the west, which introduces pulses of cold, nutrient-rich and turbid water into the shallow reef areas. High-resolution temperature records revealed that these solitons occurred during the temperature rise and acted as cold showers during temperature highs. The current monitoring of the Andaman Sea bleaching event demonstrates the importance of fully capturing the environmental background especially the underwater temperature regime and how it influences coral reef ecosystems. Factors such as species composition, sedimentation, and biological invaders can positively or negatively impact reefs during bleaching events and can make predictions even more complex. Regions with reoccurring temperature anomalies such as cold water pulses could be important for coral reef recovery by acting as refuges replenishing adjacent severely damaged reefs with new recruits. The knowledge of such environmental variability is an important requisite to predict the severity of bleaching events.

9A Coral bleaching & climate change
Tuesday 10 July, 1230, Plenary Hall 2

Working with nature to identify coral reefs with increased environmental tolerance

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Whereas direct anthropogenic pressures can be managed to best protect reef from stresses, the future of reefs is dependent on the resilience and vulnerability to environmental stressors. To date, our best management strategy to protect these ecosystems is to utilize strategies adopted by species with inherent ecological complexity and redundancy within the system. Management strategies must incorporate this to identify and protect vulnerable systems in a way that would be both effective and economically achievable. Here studies examine how system connectivity can provide insight in to overall system resilience and the benefits of coupling this with studies on how ambient environmental conditions influence susceptibility. Many studies have observed variation amongst temporal onset and bleaching severity, particularly across coral growth forms and those species inhabiting marginal environments. However, these studies have failed to identify the effect of environment on life history traits and consequently the impact of these on susceptibility. Here we test the hypothesis that the growth history of corals influences the resilience and ability for recovery when faced with environmental stressors. It has long been documented that light and temperature have a synergistic effect on stressors on coral reefs, with light intensifying the effects of increased temperature. Studies conducted in the Indo-Pacific Ocean suggest that corals inhabiting sites with greater environmental variability hold increased resilience to thermal anomalies than those in more stable habitats. We suggest that certain physiological traits may serve as indicators of sensitivity to future climatic changes.

9A Coral bleaching & climate change
Wednesday 11 July, 1015, Plenary Hall 2

Repetitive bleaching, photobiology, and *Symbiodinium* balance in three Caribbean corals

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While *Symbiodinium* physiology and genetics play a key role in determining the outcome of coral bleaching, we know very little regarding how symbiont photobiology and population distributions may change under scenarios of repetitive bleaching and recovery. Symbiont type (based on gel and QPCR analyses), as well as photobiology was followed through 2 cycles of experimental bleaching and subsequent recovery over 2 years in the corals *Montastraea faveolata*, *Porites astreoides*, and *Porites divaricata*. In year one, bleached *M. faveolata* displayed the greatest loss in photochemistry and symbiont number, which entailed a significant loss in *Symbiodinium* C7, B1 and B17. Conversely, both *Porites* species displayed greater resistance to thermal photoinactivation, but differential loss in symbiont number. In situ recovery from initial bleaching in *M. faveolata* entailed a significant increase in the percentage of *Symbiodinium* D1a, as well as A3 or A13, which conferred a greater resistance to photoinactivation during the second thermal stress. *P. astreoides* maintained the same symbiont type throughout the experiment and displayed greater photoinactivation, symbiont loss, and slower recovery in these parameters after the second bleaching. However, *P. divaricata* recovered from the initial bleaching with a combination of C47 and A4 symbionts, and displayed minimal photoinactivation once more during the second bleaching, which was followed by a large transition to the A4 symbiont in the second recovery interval. Given these differences in the physiological response and/or symbiont type here, care should be taken in determining the resilience and potential to recover from bleaching when based solely on single experiments.

9A Coral bleaching & climate change
Wednesday 11 July, 1400, Plenary Hall 2

Bioerosion of in-situ coral colonies: St. John, US Virgin Islands

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Understanding the rate at which bioerosion occurs is hampered by difficulties in constraining the time span that natural substrate degradation has proceeded over. While experiments using carbonate blocks address this issue, it is unclear how well sterile, artificial substrates placed on the reef mimic recently killed corals. A widespread bleaching event in 2005 led to a monitoring program by the US National Park Service, in which repeated video surveys along permanent transects tracked changes in coral cover and mortality, initially on a bimonthly basis and then annually as rates of change slowed. Video from these surveys was used to constrain the time-of-death for individual colonies of *Montastrea* spp. in 2 bays on St. John (US Virgin Islands) over the past five and a half years. A total of 99 samples were collected from eleven 10m long monitoring transects established along a depth gradient (4-20 m). Preliminary analyses returned macro-bioerosion rates similar to the highest values reported in the literature for long-term exposure of experimental substrates. This study provides a basis for evaluating the suitability of artificial substrates as a proxy for in-situ coral bioerosion. A more complete understanding of the rate and nature of bioerosion will improve our ability to quantify the balance between destructive and constructive processes and their impacts on reef accretion, as reefs come under increasing anthropogenic stress.

9A Coral bleaching & climate change
Wednesday 11 July, 1200, Plenary Hall 2

Phosphate starvation renders corals susceptible to thermal bleaching

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Coral reefs are threatened on a global scale by bleaching, the often fatal loss of the corals' symbiotic algae (zooxanthellae). We found that the devastating mass coral bleaching event in 1998 was preceded regionally by dramatic changes in phytoplankton biomass indicative of strong fluctuations in the availability of inorganic nutrients for the coral-zooxanthellae association. Shifting nutrient concentrations, such as increased nitrate to phosphate ratios, can induce phosphate starvation as a result of chemically imbalanced algal growth. We have developed a coral bleaching model that introduces phosphate starvation of the zooxanthellae as a primary cause for an increased susceptibility of corals to heat stress. We studied the effects of phosphate starvation of zooxanthellae in hospite under controlled laboratory conditions. Phosphate-stressed corals showed an increased susceptibility to bleaching caused by temperature and light stress, resulting in higher mortality compared to phosphate-supplemented controls. The results of our biomarker analysis explain the molecular mechanisms underlying the increased vulnerability of phosphate-stressed corals. Moreover, these results link unfavourable inorganic nutrient ratios in the water column with established

downstream mechanisms of coral bleaching and help to clarify the controversial connection between ocean eutrophication and coral reef degradation.

9A Coral bleaching & climate change
Tuesday 10 July, 0930, Plenary Hall 2

Are adjacent corals sources of *Symbiodinium* for bleached coral recovery?

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Coral reef response to climate change stressors can be influenced by the community dynamics of algal symbionts (genus *Symbiodinium*) in corals following bleaching events. Post-bleaching recovery of these communities occurs through the proliferation of existing remnant symbionts and/or the (perhaps temporary) acquisition of exogenous symbionts. Different *Symbiodinium* vary in their physiological optima, and certain types (such as some members of clade D) can help corals survive bleaching if they are sufficiently abundant within a colony. To explore whether symbiont community composition in recovering corals is influenced by symbiont communities in nearby colonies, we ran a pilot study using replicate fragments from six mother colonies each of *Montastraea faviolata* and *Pocillopora damicornis*. Experimental fragments were bleached through exposure to heat stress (32°C) and then allowed to recover in one of two temperature treatments (24°C or 29°C). During this recovery phase, bleached corals were exposed to either (1) unbleached replicate fragments; (2) previously bleached replicate fragments that had been allowed to recover at elevated temperatures and had recovered with thermally tolerant symbionts in *Symbiodinium* clade D; or (3) no other replicate fragments (exposure control). Using highly sensitive qPCR assays, we tested the hypotheses that exposure to nearby corals with thermally tolerant symbionts promotes the ability of bleached corals to recover with these symbionts, and that this process is accelerated at higher temperatures.

9A Coral bleaching & climate change
Monday 9 July, 1715, Plenary Hall 2

Examining coral bleaching through the analysis of the *Symbiodinium* transcriptome

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The cnidarian-dinoflagellate association is the major component of the coral reef ecosystem. Recently this ecosystem has suffered from changing environmental conditions. Despite the importance of coral reefs, we understand few details of coral physiology and the ways in which corals respond to changing environmental conditions. We have been developing a proxy system for the coral association in which the dinoflagellate *Symbiodinium* is introduced into a clonal population of the small sea anemone *Aiptasia pallida*. Starting with nonaxenic dinoflagellate cultures provided by others and algae isolated from their natural hosts, we have isolated 5 clonal and axenic *Symbiodinium* strains and demonstrated that at least 2 of them can successfully populate aposymbiotic *Aiptasia*. Initially, we characterized the growth and light responses of these strains coupled to their photosynthetic characteristics. These studies suggest that the strains grow best when supplemented with an exogenous carbon source and when maintained under relatively low light conditions (e.g. 10 µmol photon m^{-2} s^{-1}); elevated light levels may compromise growth. The light quality also appears to have a significant impact on growth. We are also using RNA-seq to establish a high coverage transcriptome for our *Symbiodinium* strains and to characterize gene expression in the algae under different light and temperature conditions. Ultimately, we will compare the environmental responses of the free-living dinoflagellates to those populating the cnidarian, using both the proxy system and coral nubbins from the natural environment (site in American Samoa), with the goal of developing diagnostics to determine the 'health' of a coral stand.

9A Coral bleaching & climate change
Wednesday 11 July, 1230, Plenary Hall 2

Coral and zooxanthellae selection which are resistant to global warming

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Increasing water temperatures caused by global warming has an effect on coral ecosystems and can cause the extinction of coral species. In order to rehabilitate reefs, it is necessary to have knowledge about the variety of corals that are resistant to increased water temperature. One reliable method is to identify the range of thermal tolerances among coral species. The purpose of this research is to identify the coral species which are the most resistant or adaptive to increased water temperature. This study compares the effects of water temperatures (30°C, 32°C, 34°C and 36°C) on six coral species from reefs surrounding Panjang Island and Bandengan Island. The species of coral investigated from Panjang Island are *Montipora digitata*, *Porites cylindica*, and *Acropora aspera*. The species from Bandengan Island are *Porites lobata, Pocillopora damicornis,* and *Acropora aspera. Porites lobata* from Bandengan Island were the least influenced by increasing water temperature whereas *Acropora aspera* was the worst affected. There was no correlation between location and water temperature. This fact can be seen from two other coral species which are taken

from Bandengan coast, *Pocillopora damicornis* and *Acropora aspera* which are significantly influenced by the increasing water temperature. In addition, the corals from Panjang Island were all influenced by increased water temperature.

9A Coral bleaching & climate change
Wednesday 11 July, 1000, Plenary Hall 2

9B Coral communities in extreme environments

Kuwait off-shore coral reefs and extreme environment

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Surveys were conducted during 2003-2005 on 3 off-shore Kuwaiti coral reefs (Kubbar, Qaro and Um Al Maradim) to assess coral community structure and adult and juvenile coral diversity. This revealed 45% average coral cover for all sites with no significant differences between sites or depths, and between islands, but with significantly lower species diversity found at exposed sites of each island. These shallow high-latitude reefs are characterized by low species diversity of coral (35 spp.), and a relatively high cover dominated by *Acropora* spp. and *Porites* spp. Pauci-specific assemblages are a typical condition found in other high-latitude reefs in the Arabian region. Juvenile coral density was significantly higher in sheltered sites (0.59 ± 0.44 per m²), and at deeper depths. The mean number of recruits along each transect did not exceed 1/m² except in one leeward station at Qaro where a mean number of recruits was estimated to be 1.37 ± 0.2 per m². Results of the study indicate that the offshore coral reef communities of Kuwait are experiencing extreme environmental conditions at both high and low temperatures (16°C in winter and 34°C in summer), in addition to being influenced by freshwater input from Shat Al-Arab. Being the most northerly reefs in the Arabian Gulf and the Indian Ocean System, the Kuwait off-shore reefs at Kubbar, Qaro and Um Al-Maradim are highly important reef communities and should be declared as protected areas.

9B Coral communities in extreme environments
Monday 9 July, 1030, Plenary Hall 2

The genetic diversity of coral-dinoflagellate symbioses in the Red Sea

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The isolation and broad range in environmental conditions of the Red Sea make it a natural laboratory to study key questions about the evolution and ecology of coral-dinoflagellate associations. We analyzed the symbiosis diversity and ecology among reef corals belonging to the family Pocilloporidae (*Seriatopora*, *Stylophora* and *Pocillopora*). The genetic diversity of the coral and that of the symbiont were examined over depth (1-20m) and latitudinal gradients extending from the Gulf of Aqaba (Maqna, 28°31'N to 28°31.3'N, 34°48'E to 34°15.9'E) to the Farasan Islands (16°34'N to 16°46.2'N, 42°08'E to 42°57.8'E). *Symbiodinium* diversity was characterized using a combination of ribosomal ITS2 data and direct sequencing of the non-coding region of the psbA plastid minicircle, while host identity was verified using sequences of the mitochondrial open reading frame (ORF). *Symbiodinium* microdriaticum (*sensu stricto*, a.k.a. type A1), was the most common symbiont in all three genera. However, its association with members of each host genus varied considerably with respect to depth and latitude. For example, in northern regions shallow dwelling colonies of *Stylophora* spp. harbored A1, while deeper colonies contained one of 3 different host specific Clade C lineages (C160, C161 and C162). In contrast colonies of Pocillopora harbored only A1 at all depths and latitudes. The ecological dominance of a *S. microadriaticum* in these corals is highly unusual relative to the rest of the Indo-Pacific and emphasizes the unusual ecological and evolutionary adaptations of coral-dinoflagellate symbioses found in the Red Sea.

9B Coral communities in extreme environments
Monday 9 July, 1530, Plenary Hall 2

Patterns of coral recruitment in an extreme environment: Persian Gulf

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Coral reefs in the Persian Gulf survive in one of the most extreme environments for reef corals anywhere in the world; however, our knowledge on important ecological processes, such as coral recruitment, is limited. In this study, we examined spatial and temporal patterns of coral recruitment on shallow (4-5m depth) reef patches at 7 sites along ~45 km of coastline in Dubai, U.A.E. (24°N) from 2009-2011, to examine whether coral recruitment in the southern Persian Gulf is comparable to other coral reef locations.

Recruitment varied significantly among sites and seasons, with a significant interaction driven by differences among seasons that varied between sites. Recruitment was highly seasonal with peak recruitment in the summer (June-August), followed by a minor recruitment period in the autumn (September-November). Recruitment during the summer was highest with a mean of 3.25 ± 0.19 SE recruits tile-1 compared to 0.28 ± 0.04 SE recruits tile-1 in the autumn. The most common recruits identified in this study belonged to the families, Poritidae (26%) and Acroporidae (9%); however the majority of recruits (65%) could not be identified to a particular family. Overall, coral recruitment in the southern Gulf was low (85 recruits $m^{-2}yr^{-1}$) compared to most tropical reefs, but similar to levels reported from other sub-tropical reef locations suggesting that corals in the southern Gulf are adapted to the extreme environmental conditions.

9B Coral communities in extreme environments
Monday 9 July, 1215, Plenary Hall 2

Setting coral salinity thresholds for mapping freshwater flood plumes

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Freshwater runoff is a major source of coral mortality, especially on coastal reefs close to river systems. Determining salinity thresholds is important for mapping and modelling the extent and impact of flood plumes as a result of river runoff. Despite considerable experimental work on salinity tolerance limits of corals nearly 100 years ago, very little new work has been done and little that can be used in a practical exercise of mapping flood impacts. This study will review the work that has been done on hypo-osmotic tolerance in corals and will present tolerance limits derived empirically from loggers deployed during a major flood event in early 2011 in the Keppel Islands on the Great Barrier Reef. We show that based on observed differential mortality of the sensitive coral genus *Acropora*, the threshold is a time-dose curve with a salinity-sensitive range of between 28-21 PSU. At the higher end of this range most *Acropora* species can tolerate exposure periods of up to 16 days. At the lower end of the salinity range, exposures of 2 days will cause widespread mortality. The proposed time-dose curve was tested against a coral community >1000 km to the north which was similarly monitored during the same coastal runoff event. The results are consistent with the Keppel Island time-dose curve giving confidence in the region-wide application of this threshold for the purpose of modelling the impacts of flood events.

9B Coral communities in extreme environments
Monday 9 July, 1500, Plenary Hall 2

Long-term bleaching impacts on the worlds warmest reefs

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The southern Arabian Gulf houses some of the most thermally tolerant corals on earth, but severe bleaching in the late 1990s caused widespread mortality, particularly in formerly dominant *Acropora* spp. More than a decade later, corals still dominate benthos (mean: 40 ± 3% cover on 10 sites spanning >350 km; range: 11.0-65.6%), but community composition has shifted towards Poritid and Faviid dominance and the magnitude of long-term impacts varied spatially. Western sites generally had low species richness and coral cover (mean: 3.2 species per 30 m transect, 31% cover), with *Porites* dominated communities (88% of coral) that are distinct from more diverse and higher cover eastern sites (mean: 10.3 species per transect, 62% cover). These patterns reflect both the more extreme bleaching to the west in the late 1990s as well as the higher Faviid dominated recruitment to the east in subsequent years. There has been limited recovery of the formerly dominant *Acropora*, which now represents <1% of the benthos overall, likely as a result of recruitment failure. Quarterly recruitment to terra cotta tiles over 2 yr showed peak recruitment in summer (mean: 3.3 ± 0.5, range: 0-14.9 per tile; n=25 tiles/site, 10x10 cm each), but this recruit density was generally low compared with other regions. Recruitment was characterized by high spatial variability and lack of relationship with site-specific coral cover. Results indicate that severe bleaching can have substantial long-term impacts on coral communities, even in areas with corals tolerant to environmental extremes.

9B Coral communities in extreme environments
Monday 9 July, 1545, Plenary Hall 2

Coral resilience to extreme tidal induced environmental fluctuations

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To evaluate how corals have adapted or acclimatized to large-scale 'natural' fluctuations in their environment we have examined corals from a study site located near the tip of the Dampier Peninsula in the Kimberley of NW Australia. This site experiences the largest tidal range of any tropical region in the world (11.7 m), forming functionally isolated pools at low tide. The semi diurnal tidal cycle causes the environmental conditions to fluctuate; as a result corals experience high maximum temperatures of up to 35°C during daytime spring low tide, as well as periodically being subjected to high levels of irradiance. Temperature induced stress and the synergistic effect of elevated temperature and high irradiance are some of the main factors responsible for coral bleaching, a consequence of the expulsion of symbiotic algae. In marked contrast to most coral

reef environments where elevated temperature as little as 1-2°C over mean summer maximum, lead to a loss of symbionts; compared to what the Kimberley corals experience, this is a change of relatively few degrees over months, we have observed temperature changes of 7-8°C over a single tidal cycle. The rate of temperature elevation itself has been shown to induce additional stress. However the corals examined here appear to be well adapted to these extreme conditions, as shown by survival and growth-rates. Understanding this extraordinarily high resilience has potentially important implications for the longer-term resilience of coral reefs to the thermal stress expected in response to climate change in the coming decades.

9B Coral communities in extreme environments
P099

Responses of gulf corals to temperature stress

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Corals of global relevance such as the genus Porites can exist in habitats with extreme sea water temperatures in the Arabian/Persian Gulf region featuring high temperature maxima and strong temperature fluctuations. The temperature conditions in these habitats are comparable to those predicted for parts of the world's oceans in the next century. Hence, corals from the Gulf region can serve as excellent models for the adaptation potential of reef corals to rising ocean temperatures. Laboratory experiments under tightly controlled conditions can facilitate studies of the molecular basis of their resistance towards temperature stress and to establish the specific contributions of the coral host and algal symbionts. We have set up long-term aquarium cultures of *Porites lobata* from Abu Dhabi and Fiji waters. *P. lobata* from Fiji hosts C15-type zooxanthellae whereas the Abu Dhabi specimens are associated with a range of subclades similar to clade C3. These results are surprising as C15, rather than C3, is considered to be a thermotolerant strain. We will present the results of a study that compares the responses of *P. lobata* form Abu Dhabi and Fiji to temperature stress.

9B Coral communities in extreme environments
Monday 9 July, 1230, Plenary Hall 2

Susceptibility of Red Sea corals to a major bleaching event

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We observed a major coral bleaching event in the central Red Sea near Thuwal, Saudi Arabia, in the summer of 2010. The region experienced 10-11 degree heating weeks. In order to quantify bleaching vulnerability, we documented: a) the susceptibility of various coral taxa to bleaching during the peak of this thermal stress and b) subsequent mortality 7 months later. Oculinids and agaricids were most susceptible to bleaching, with these families showing up to 100% and 80% (respectively) bleaching at some sites. However, some groups, such as Mussids, Pocilliporids, and Pectinids showed low levels of bleaching (<20% on average). After bleaching, 7 months later, we estimated subsequent mortality due to the bleaching event. Mortality was highly variable among taxa, with some taxa showing evidence of full recovery (e.g. Fungiids) and some apparently suffering nearly complete mortality (e.g. Acroporids). These disproportionate effects among groups resulted in significant community composition change on some reefs following the bleaching events. Increasing depth and increasing distance offshore both generally decreased the likelihood of bleaching. This bleaching event shows that even Red Sea reefs, considered by many to be tolerant of extreme conditions, are not immune to increasing global pressures. To our knowledge, this study represents the first assessment of the vulnerability to bleaching of various coral groups (genera or families) from within the Red Sea. Understanding the relative susceptibilities of taxa from this region of extreme conditions offers valuable insights and informs efforts to model future reef communities in the Red Sea and Arabian Gulf.

9B Coral communities in extreme environments
Monday 9 July, 1145, Plenary Hall 2

Socotra (2000-2011): recovery, resilience and refugia in an upwelling environment

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The Socotra Archipelago, situated at the north-west extreme of the Indian Ocean, is exposed to upwelling during the south-west monsoon and seawater temperatures can range from <21 to >31°C. Despite the seasonal variability, the Archipelago supports high diversity coral communities and higher live hard cover than found on many lower latitude biogenic reefs. Coral bleaching related mortality occurred in 1998 due to sustained high seawater temperatures over a period of 18 months (May 1997 to November 1998). Coral

dominated communities around the outer islands were less affected than those around the main island of Socotra due to spatial variability in the upwelling. Permanent monitoring sites, established in 2000 as part of a UNDP-GEF funded project, have been maintained and surveyed annually by the local marine team from the Environment Protection Authority, with more detailed surveys in 2003, 2007, and more recently in 2010 and 2011. Hard coral cover has increased or remained stable around the outer islands (to 2007) and increased significantly ($p<0.001$) by 15% to >50% at 5 out of the 6 sites (to 2010) on the north east coast of Socotra (mean cover = 44.6% ± 3.8 SE). Recovery is due largely to the rapid colonisation by bleaching susceptible Acroporiids and *Stylophora* spp. Coral cover declined at one site due to human-induced impacts. The results reveal the resilience of these types of marginal coral community and highlight the importance of refugia created by upwelling environments in supporting recovery processes (which should be critical targets for conservation).

9B Coral communities in extreme environments
Monday 9 July, 1515, Plenary Hall 2

A short-term exposure to elevated temperature on coral mesocosm study

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Global climate change stands to severely damage coral reefs, yet this claim is based on the results of microcosm studies focused on only one organism. In fact, a mesocosm approach may provide a more realistic framework in which to document the impacts of changing environments on marine organisms. As such, multiple ecological functional groups were cultured in 600L mesocosms in order to simulate the local coral reefs of southern Taiwan, and afterwards, an elevated temperature experiment was conducted over the course of 4 weeks in order to understand how one common, Taiwanese reef coral, *Pocillopora damicornis*, acclimates to increases in temperature. Corals were sampled at various intervals across the experiment and a variety of molecular, cellular, and physiological parameters were measured. While neither coral growth nor chlorophyll *a* concentration differed between treatments, nubbins sampled later in the experiment tended to exhibit higher growth rates, suggesting that even corals of the high temperature treatment were able to acclimate. The Fv/Fm data also seem to suggest acclimation, a surprising finding given that results of microcosm studies have repeatedly revealed extensive photoinhibition, and even death, of corals exposed to temperatures above 29.5-30°C. It is hoped that the impending cellular (histological sectioning) and molecular (gene and protein expression) data will shed light on how these corals managed to acclimate to temperatures that have previously been shown to be not only stress-inducing, but also fatal, for most reef corals.

9B Coral communities in extreme environments
Monday 9 July, 1015, Plenary Hall 2

PAM chlorophyll fluorometry for monitoring health of corals along the coast of Qatar

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The Arabian Gulf is shallow, sub-tropical, and semi-enclosed, all factors that promote considerable variations in the properties of its water. A 2 year-long study was conducted to evaluate the effectiveness of PAM (Pulse Amplitude Modulation) chlorophyll a fluorometry in monitoring the health of coral reefs. The objectives were: (i) to evaluate the efficacy of PAM chlorophyll fluorometry as a means of assessing sub-lethal stress in corals; (ii) to calibrate and validate this technique for future monitoring applications; (iii) to collect environmental data to correlate detected changes in stress status to changes in the magnitude of environmental factors that are known to affect these organisms. The study consisted of 6 field surveys conducted over 25 months. PAM fluorometry measurements were completed with detailed visual assessments of the health status of the corals. While the visual signs of stress were difficult to quantify, the PAM fluorescence data provided a clearer indication of stress being experienced at the time of the surveys. The reduced photosynthetic efficiency indicated by the PAM, without clear visual signs of degradation, was generally followed by necrosis of parts of the colonies, visually verified in subsequent campaigns. Moreover, corals experienced severe bleaching during summer 2010 and PAM fluorometry data allowed a detailed analysis of the process including recovery. This study demonstrated that PAM fluorometry can improve our ability to monitor the health of corals in the Qatar and Gulf environment by providing objective data on the photosynthetic performances and the state of stress of these organisms.

9B Coral communities in extreme environments
Monday 9 July, 1115, Plenary Hall 2

Extreme heat-adaptability and coral population responses to climate extremes

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By 2099, tropical ocean temperatures will have increased by 1-3℃ by, and many coral reefs may have succumbed to bleaching. Arabian/Persian Gulf corals already exist today in this future thermal environment, offering insights into future dynamics across the tropics. These reefs survived bleaching in 2010 and 2011 when exposure to 33-35℃ was on average twice as long as in non-bleaching years. Gulf corals bleached after exposure to temperatures above 34℃ for a total of 8 weeks of which 3 weeks were above 35℃. This is more heat than any other corals can survive, and represents present maximum of holobiont adaptation. Average temperatures and heat-waves in the Gulf have increased and as a result, coral population levels will fluctuate strongly, and reef-building capability will be compromised. This, in combination with ocean acidification and rampant coastal development puts even these most heat-adapted corals at risk. WWF considers the Gulf ecoregion as critically endangered. Gulf corals and any other coral population adapted to extremes should be considered valuable potential broodstock for assisting thermal adaptation in other regions. In the Gulf, heat-adaptation was acquired over 6k years, but tropical Indo-Pacific corals have <100 y until they will experience a similarly harsh climate. Modelled population trajectories clearly show impending community changes within regional faunas and indicate potentially vastly superiory performance if heat-adapted corals from an extreme environment were to come to settle on what is now a typical tropical reef.

9B Coral communities in extreme environments
Monday 9 July, 1000, Plenary Hall 2

Comparing coral species composition between man-made and natural backreef pools

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Flow-restricted backreef pools are uncommon in American Samoa, due to reef crests being close to the shoreline. Students at the American Samoan Community College have studied the coral species composition within the man-made pools that were blasted to form the Pago Pago airport runway by the Navy in the 1940s. The species composition will be compared to that found in the naturally occurring backreef pools found around Tutuila in Taputimu and Vatia, and later to pools along the south coast of Ofu Island. The Ofu pools are much studied due to their resiliency to thermally induced bleaching as well as large pH (up to 1 unit) and salinity (up to 10 ppt) perturbations. Coral cover remains high within these pools despite these challenging conditions. The airport pools are the deepest (approx. up to 8 m) and contain many branching Acroporid thickets, while the other pools are dominated by boulder corals that appear to be more resistant to bleaching. Studies conducted in the Ofu pools have failed to find a particular factor to attribute this resistance and continued resilience to, but instead have hypothesized that the species found therein have evolved to their unique environment. By studying the species composition of the manmade pools and comparing it to those found in naturally occurring pools, we hope to gain a unique perspective on this evolutionary process by determining how the species composition differs.

9B Coral communities in extreme environments
P100

Southern frontiers: ecology of subtropical coral communities of southeast Australia

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Climate change is projected to alter environmental conditions of high-latitude reefs, with likely impacts on species ranges, community composition and reef health. Knowledge of their temporal and spatial ecological dynamics and the mechanisms that control community assembly is required before climate change impacts on marginal reefs and implications for their management can be fully assessed. Coral communities south of the Great Barrier Reef, on the east coast of Australia, exist at or near the southern limits of hermatypic coral distribution under highly fluctuating environmental conditions. Benthic communities were quantitatively investigated in photographic transect surveys at 21 reefs along a gradient of eight degrees latitude (24°48'-32°48'S) in 2010 and 2011. Significant latitudinal and inshore to offshore differences in coral and benthic communities were recorded. Although coral species richness generally declined with increasing latitude, the same pattern was not observed for abundance, as some southern reefs had high cover despite low richness. Coral communities were characterised by *Turbinaria*, *Goniastrea* and *Acanthastrea* species that tend to be rare on tropical coral reefs. *Acropora* spp. were most abundant offshore. Benthic communities showed unique biogeographical composition, including temperate taxa such as the coral *Coscinaraea mcneilli*, the echinoid *Centrostephanus rodgersii*, and the kelp *Ecklonia radiata*. Observed patterns of species distribution and abundance were inferred to reflect environmental differences associated with oceanographic features and nearshore processes and their influence on temperature, nutrient concentrations and light availability.

9B Coral communities in extreme environments
Monday 9 July, 1200, Plenary Hall 2

Effects of coral bleaching and recovery potential of coral reefs at Mu Koh Surin, the Andaman Sea

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Elevated seawater temperatures in summer months of 2010 were associated with widespread coral bleaching in the Andaman Sea. The present study examines the impact of coral bleaching and recovery potential of coral reefs at Mu Koh Surin National Park, Thailand. The percentages of dead corals following the bleaching event for all 10 study sites were over 50%. The highest percentage of coral mortality was at Hin Pae (71.3%) while the lowest one was at Ao Tao (53.9%). Most *Acropora* and *Pocillopora* colonies were affected and their mortality rates were very high (>90%). Spatial variation in coral bleaching and subsequent mortality was clearly observed with reflecting differences in depth, reef profile and water flow. The densities of coral recruits were relatively high (6.1-11.0 recruits m^{-2}). The major groups of coral recruits were also high taxonomic diversity, including *Acropora* spp., *Fungia* spp., *Favia* spp., *Favites* spp., *Goniastrea* spp., *Platygyra* spp., *Diploastrea heliopora, Cyphastrea* spp., *Porites* spp., *Coeloseris mayeri, Gardineroseris planulata, Pachyseris* spp., *Ctenactis* spp., *Lithophyllon* sp., *Pectinia* sp., *Turbinaria* spp., *Astreopora* sp., *Montipora* spp., *Pocillopora* spp. and *Galaxea* spp. Certain coral communities at Mu Koh Surin exhibit recovery potential after the coral bleaching event therefore the appropriate management plan for protection of these coral communities is urgently needed in order to ensure the sources of coral larvae for coral recovery in the Andaman Sea.

9B Coral communities in extreme environments
Monday 9 July, 1130, Plenary Hall 2

9C Ecology of mesophotic coral reefs

The role of deep reefs in shallow reef recovery

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The unprecedented decline in shallow coral reef communities has led to a growing interest in deep reefs, or mesophotic coral ecosystems (MCEs), and their ability to function as local refugia and sources of recruitment after disturbance. Nonetheless, the extent of connectivity between shallow and deep reef communities remains uncertain. Here, we summarize a range of molecular (population genetic and phylogenetic) and experimental (transplantation and larval preference) studies, in which we assess (a) the extent of genetic overlap between shallow and deep coral communities and their associated *Symbiodinium*, (b) the roles of both pre- and post-settlement selective processes in vertical connectivity, and (c) the occurrence of physiological adaptation to the deep reef environment. Although we found some evidence for recruitment of larvae from deep water into shallow reef habitats, both the genetic surveys and experimental work indicated that the potential for vertical connectivity differed strongly between species and localities. Overall, depth-associated environmental conditions appear to pose strong selective forces on coral communities, which may hamper vertical connectivity particularly in coral species with a brooding reproductive mode. Nonetheless, further research on vertical connectivity across a broader range of species is required to infer levels of connectivity on a community level. The frequent observation of genotypes in low abundances outside their natural distribution range, however, indicates that deep reefs may play an important role in the local preservation of genetic diversity. This remains a hopeful aspect of coral reef biology as reefs enter a century of human and climate driven change.

9C Ecology of mesophotic coral reefs
Tuesday 10 July, 1200, MR5

Predicting the distribution and spatial extent of mesophotic coral reef habitat on the Great Barrier Reef

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Predictive habitat models are an increasingly important tool for scientists and managers for identifying the distribution of species and/or communities which have not been extensively sampled, such as rare or cryptic species or communities in inaccessible habitats such as the deep-sea. Mesophotic coral reef ecosystems (MCEs) are coral reef communities which occur in the lower photic zone. Because they occur below the depths accessible to traditional SCUBA surveys, the ecology of MCEs is poorly known. However, recent studies have indicated that MCEs contain unique ecological communities, may provide important spawning sites for a variety of fish species, and may be less susceptible to environmental disturbances such as warm-water bleaching events and tropical storms. Therefore,

MCEs may play a vital role in the resilience of coral reef ecosystems, and may provide vital refugia for corals and associated species from the effects of climate change. Here, we use environmental data to identify potential mesophotic reef habitat for two community types (phototrophic- and heterotrophic-dominated benthic communities) at two spatial scales in the Great Barrier Reef World Heritage Area (GBRWHA), Australia. The results indicate that over 7000km^2 of MCE habitat occurs in the GBRWHA, of which only 763 km^2 is currently documented as reef habitat by reef management. Identifying potential MCE habitat which may provide refugia for coral reef species from environmental stress should be a priority for coral reef scientists and managers in coming decades to ensure their adequate protection.

9C Ecology of mesophotic coral reefs
Tuesday 10 July, 1145, MR5

Importance of the coral genus *Leptoseris* to mesophotic coral communities in the Indo-Pacific

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The vast majority of coral reef research has focused on shallow-water reefs easily accessible by SCUBA diving, although technological advances in recent years have resulted in an increased interest mesophotic coral communities which occur in the lower photic zone. To date, few studies have focussed on mesophotic coral reefs in the Indo-Pacific, and consequently few consistent patterns have been detected among coral reef communities in the region. However, zooxanthellate corals of the genus Leptoseris appear to be ubiquitous members of deeper mesophotic communities across the Indo-Pacific. The genus has been observed growing at depths >100 m in several locations, and may provide vital habitat complexity for unique fish and mobile invertebrate communities at mesophotic depths. Despite its abundance and widespread occurrence on mesophotic reefs, exactly how Leptoseris survives over such a wide depth range is not clear. Here, we look at the taxonomy and biogeographical distribution patterns of *Leptoseris spp.* on mesophotic reefs in the Indo-Pacific (Australia, Hawaii and the central Pacific islands) and investigate aspects of its symbiosis that enable it to dominate habitats inhospitable to other zooxanthellate corals. Genotyping of *Symbiodinium* associated with Leptoseris corals from the Great Barrier Reef and Hawaii indicated that these specimens hosted symbiont types that are commonly found in shallower water. Nonetheless, some of the observed host-symbiont combinations represented novel associations, transcending previously known patterns of host-symbiont specificity. This study highlights the current taxonomic uncertainties with the genus Leptoseris and poses several hypotheses for the ecological success of the genus at mesophotic depths.

9C Ecology of mesophotic coral reefs
P101

Temperature related lower depth limits for tropical corals in Hawaii

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In coral reef ecosystems, depth zonation of sessile benthic fauna can be attributed to several physical environmental factors which change predictably with increasing depth. For ectothermic tropical organisms, exposure to low temperature thermal stress has been shown to limit their geographic distribution at high latitudes. An analogous decrease in temperature with depth eventually limits depth distribution of tropical organisms which are not first limited by other factors. In the Au'au Channel in Hawaii, the dominant megabenthic organisms including azooxanthellate corals exhibit distinct vertical zonation with marked change in fauna in the vicinity of the seasonal thermocline at 110-120m. Below these depths, passive suspension feeders of closely related taxa with similar morphologies remain abundant indicating that food for obligate heterotrophs is not limiting. These observations suggest that lower depth distribution limits for tropical, non-photosynthetic, sessile benthic fauna are likely due to expose to low temperature stress. In general, little is known about the thermal thresholds dictating lower depth distribution of tropical fauna. The objectives of this study were to (1) characterize the relationship between temperature regime at the lower depth limits of tropical corals on a mesophotic reef in Hawaii, (2) test whether lower depth limits were consistent with chronic low temperature stress or acute low temperature disturbance, and (3) identify a low temperature threshold which may be used to predict lower depth limits for tropical Hawaiian fauna throughout the archipelago.

9C Ecology of mesophotic coral reefs
Tuesday 10 July, 1130, MR5

Trophic structure of mesophotic fish assemblages in the northwestern Hawaiian Islands

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Mesophotic coral ecosystems, also known as the coral-reef twilight zone, are receiving increased attention from coral-reef ecologists because of their potential contributions to tropical biodiversity, and because of the potential to serve as refugia for fishes that are depleted due anthropogenic activities on shallow reefs. However, the composition and trophic structure of these fish communities are poorly characterized. Here we present the results of the first transect-based mesophotic coral reef fish assemblage assessments from the Northwestern Hawaiian Islands (NWHI), and compare these results to the structure of corresponding shallow reefs of the NWHI. Each fish species was assigned to one of seven feeding guilds (corallivore, herbivore, mobile invertebrate feeder, omnivore, piscivore, sessile invertebrate feeder or planktivore). Shallow reefs (<30 m) were dominated by herbivores and mobile invertebrate feeders (primarily acanthurids and labrids). Deep reefs (50-80 m) were dominated by planktivorous species (primarily small-bodied anthiinines, chaetodontids, and pomacentrids). The abundance of herbivorous species on shallow reefs, and their relative absence on deep reefs, may be due to the difference in PAR (and hence primary productivity) between the two habitats.

9C Ecology of mesophotic coral reefs
Tuesday 10 July, 1245, MR5

Mesophotic coral reefs: a global model of structure and function

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Mesophotic coral reefs (MCRs) are an understudied continuum of shallow coral reef communities at depths of 30 to 150 m. These reefs are subject to gradients of light and nutrients that results in changes to the community structure and function with increasing depth. The upper mesophotic reef is largely comprised of many of the same species that are found in shallow coral reef systems. However, the lower mesophotic reef, below about 60 m, has reduced biodiversity and often a replacement of corals and algae with sponges. Additionally, the fish fauna appears to be specialized to these intermediate depths, and to the available food resources. Thus, the upper portions of MCRs have the potential to function as refugia for shallow benthic reef species that are subject to disturbances in the top 30 m of the water column. However, MCRs may be less stable than previously reported. Recent evidence from Caribbean reefs show that MCR community structure can change in as little as 3 years after decades of stability. Studies of fish spawning aggregations on MCRs have demonstrated the ecological importance of these sites to larval connectivity with shallow reefs, but recent molecular data shows significant genetic structure of corals at mesophotic depths over broad geographic ranges, as well as strong population genetic structure of conspecifics over the mesophotic depth range. Despite site-specific differences in MCR community distribution and abundance, our data support a general model of structure and function that is equally applicable to MCRs in the Atlantic and Pacific.

9C Ecology of mesophotic coral reefs
Tuesday 10 July, 1115, MR5

Mesophotic coral reef ecosystems of the Mariana Archipelago

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Results from optical surveying in the Mariana Archipelago provide information on mesophotic coral reef ecosystems (MCEs) there. Living scleractinian coral reefs at mesophotic depths (30-150+ m) were documented at 12 of the 17 islands and banks surveyed. The older, southern islands had higher mean values of coral cover but percentages dropped to zero below 110 m. This observation is most likely attributable to the predominance of sandy sediments, which cover an average of more than 80% of the seafloor below that depth. Corals were found slightly deeper around islands at the northern end of the archipelago, and percent cover of crustose coralline algae and non-scleractinian corals below 110 m were greater in the north. Lower mean percentages of coral cover at northern islands are hypothesized to be due to their small size, steep bathymetry, and lack of the well-developed carbonate platforms found around the southern islands. Five of the nine northern islands experienced volcanic activity within the last century, which is also likely to negatively impact mesophotic reefs. A reef complex, co-located with Garapan Anchorage on a terrace off the west coast of Saipan, features the most extensive network of MCE reefs in this archipelago. A large stand of *Euphyllia paraancora*, a species petitioned for listing under the U.S. Endangered Species Act, is located at the edge of this terrace and appears overgrown by macroalgae in places. This area was also host to a diverse coral reef fish community when sampled with baited video cameras.
9C Ecology of mesophotic coral reefs
Tuesday 10 July, 1230, MR5

Genetic connectivity of *Symbiodinium* and its coral host *Agaricia lamarcki*

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The Caribbean mesophotic coral ecosystems (reef habitats found between 50 and 100m depth) and their shallow water counterparts provide a unique system to examine the patterns of genetic connectivity for scleractinian corals and their algal symbionts (*Symbiodinium* spp.). The coral *Agaricia lamarcki* harbors symbionts and inhabits both shallow and mesophotic habitats. Host-symbiont associations and patterns of genetic connectivity for *A. lamarcki* were estimated among shallow (<25m) and mesophotic populations (50-70m) of Mona Island, south-western Puerto Rico, St. Thomas, and St. Croix (USVI). Connectivity patterns were examined with microsatellite markers. DNA sequences of the *Symbiodinium* communities were obtained using the internal transcribed spacer of rDNA (ITS2). The presence of multiple *Symbiodinium* lineages within a coral host was determined by molecular cloning of the ITS2 region. The majority of *Symbiodinium* sequences recovered belonged to Clade C. There was a significant depth partitioning within Clade C, suggesting the presence of shallow and deep specialists. Our data tests the hypothesis that mesophotic corals harbor different *Symbodinium* communities than shallow water counterparts.

9C Ecology of mesophotic coral reefs
Tuesday 10 July, 1215, MR5

9D Refuges for corals in time & space

Thermal spatial heterogeneity and coral bleaching: implications for habitat refuges

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Mass coral bleaching/mortality, due to elevated seawater temperature (ST) anomalies, is increasing in intensity and frequency worldwide. However, coral bleaching/mortality at a finer scale, example within a reef, have yet to be thoroughly examined. This study compares coral bleaching and underwater temperature/light from November 2010 till March 2011 using data loggers deployed at three stations: near the coast (S1); in the middle of the lagoon (S2); and on the reef flat (S3), at Flic-en-Flac (FEF) and Belle Mare (BM). At FEF STs were above 31°C for S1 since late December 2010, and for S2 and S3 since late January 2011, while at BM such STs for S1 occurred since mid January 2011, and for S2 and S3 in late February 2011. Moreover, the number of observations of maximum STs of 32°C or above was 4 at S1 in late February 2011 and none at S2 and S3 for BM, while at FEF, number of observations of STs of 32°C or above was 5 at S1 and 1 at S2 in late February 2011 and none at S3. However, at the end of March 2011, bleaching of *Acropora muricata* was observed only at S2 and S3, and no bleaching was observed at S1 at both FEF and BM. These results indicate that though the coral *A. muricata* were exposed to higher maximum STs near the coast, it did not experience bleaching compared to the lagoonal and reef flat sites and thus suggest potential occurrence of thermal habitat refuges within coral reefs.

9D Refuges for corals in time & space
Friday 13 July, 1430, Hall A

Investigating the role of coral disease in a potential reef refuge

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Coral disease has proven a significant factor in structuring shallow coral communities in recent decades. In the US Virgin Islands, disease outbreaks following the 2005 mass bleaching event led to major declines in coral cover on shallow reefs, including on those afforded the highest management protection from human activities. Extensive mesophotic coral ecosystems of high coral in the same region experienced much less visible bleaching due to a habitat refuge, but were similarly affected by disease outbreaks during recovery from bleaching. These mesophotic reefs represent potential refugia for shallow coral communities that are heavily impacted by onshore development activities and fishing but they may not survive predicted increases in the frequency and intensity of coral bleaching and disease events. This study combined quantitative field measurements with mathematical and simulation modelling to understand what properties of these mesophotic reef systems make them more or less vulnerable to coral disease versus shallow reefs. In mesophotic depths lesion expansion rates on colonies were lower but greater numbers of corals were affected. Total mortality due to disease was rare in both habitats, with partial mortality being more typical. Modelling results suggest that left skewed size structures found at mesophotic depths were more resilient to impacts from disease. Though there was evidence to suggest that these mesophotic systems live at the edge of coral physiological tolerance, several aspects of their structure that are no longer present in shallow systems show resilience to impacts from disease.

9D Refuges for corals in time & space
Friday 13 July, 1115, Hall A

Can cyclone induced cooling offer refuge to thermally stressed corals?

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Rising sea surface temperatures (SSTs) in the tropics have been linked to a growing frequency of mass coral bleaching events. A key conservation

management goal is to identify coral reef communities that might be resistant and/or resilient to thermal stress due to favourable physiological (e.g. thermally tolerant symbionts) and environmental (e.g. local upwelling) factors. Although tropical cyclones (TCs) are known for their damaging effects on reefs, it has been shown that the nearby passage of a TC can reduce the severity and duration of coral bleaching. TCs leave behind a cool wake (SST reductions up to 6°C) that spans hundreds of kilometres from the storm centre (typically beyond the zone of damage) and can persist for weeks. To investigate the past influence of TCs on thermal stress levels at coral reefs, a 25-km resolution global dataset (spanning 1985 to 2009) of TC-induced cooling was created using historical TC and satellite SST data. TC cooling was then contrasted with historical thermal stress data (maximum annual degree heating weeks) across all reefs. In reef areas where TCs occur, significant variability was observed in the magnitude of cooling and its effect on thermal stress at both reef and regional scales. Here, we discuss these results and the likelihood that TCs could provide corals with temporary refugia from thermal stress in the future.

9D Refuges for corals in time & space
Friday 13 July, 1400, Hall A

Reefs of last resort: locating and assessing thermal refugia in the wider Caribbean

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During the past 50 years, global temperatures have risen by 0.13°C/decade, but in the Caribbean warming trends are faster still (about 0.29°C/decade). In the face of this threat, some researchers have proposed that reefs may survive only in locations of naturally low thermal or radiative stress, and have hypothesised that such refugia may be located in: (1) deep areas; (2) areas of strong mixing; (3) sites with high level of shading; (4) upwelling areas; and (5) high-latitude areas. The possible existence of thermal refugia was first articulated by Glynn in 1996, and since then it has surfaced intermittently in the literature. However, with the exception of deep reef areas, formal assessment of the efficacy of these putative refugia is lacking. Here we tested the four remaining hypotheses in the wider Caribbean region using remote sensing data and spatial predictors. We began by determining the location of the hypothesised refugia, and then quantified the extent to which they minimize chronic and acute thermal stress in a significant and consistent manner through time. We showed that in most cases the proposed areas do not constitute meaningful refugia from thermal stress. The onset of rapid climate change has driven a comparatively rapid evolution of paradigms in coral reef ecology. Given the magnitude of the burgeoning threat, it is crucial that the utility of potential solutions is assessed swiftly and thoroughly, that we may gain maximum use of the limited time available to respond.

9D Refuges for corals in time & space
Friday 13 July, 1230, Hall A

Physical processes in a mesophotic coral refuge across bleaching events

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High water temperatures and high levels of irradiance are known to trigger mass bleaching events in shallow-water corals. Mesophotic coral ecosystems (MCE) are thought to provide a refuge for some shallow-water species of corals because they generally experience lower temperatures and irradiances than shallow reefs, and in some cases may provide more opportunities for heterotrophic feeding. In this study, we compare several aspects of shallow-water and mesophotic reef environments that may either provide a refuge or contribute to stress in corals. We examine bio-physical data collected around the US Virgin Islands from 2004 to the present, including catastrophic and minor bleaching events in 2005 and 2010, respectively. We explore the driving processes of several variables, including temperature, salinity, pH, depth and strength of the chlorophyll maximum layer, dissolved oxygen concentrations, turbidity, and current velocities. Within the same depths we find high variability in the processes affecting the refuge potential of MCE, including internal wave cooling. We discuss how changes in these variables, alone or in concert with others, may affect the patterns of bleaching and mortality seen in the last decade and how changes in these variables with time may affect the refuge potential of MCE.

9D Refuges for corals in time & space
Friday 13 July, 1445, Hall A

Flower Garden Banks: a refuge in the Gulf of Mexico

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The East and West Flower Garden Banks contain the northernmost coral reefs in the continental United States and are part of a discontinuous arc of reefs and banks along the outer continental shelf in the Northwestern Gulf of Mexico. They are located approximately 110 nautical miles south of the Texas/Louisiana border, and are managed by NOAAs Office of National Marine Sanctuaries. These deep, remote reefs thrive in an unlikely area,

near the physiological edge of conditions required by hermatypic corals. The coral reef caps, which are dominated by large boulder corals at over 50% coral cover, harbor relatively healthy populations of associated fish and invertebrates. Mesophotic coral reefs thrive at depths to 50 meters and display an extraordinary 70% coral cover. The presence of healthy coral reefs in the northern Gulf of Mexico provides evidence for an area of potential ecosystem refuge in a changing environment. The latest data from a 20-year long term monitoring program of the Flower Garden Banks will be presented, along with trends and possible stressors that may threaten the high level of health of these reefs. Other coral reefs and coral communities in this region will be described, such as the mesophotic coral reef found at McGrail Bank. Environmental factors that may favor future coral reef development in this region will be discussed. In an era of global decline in coral reefs worldwide, the Gulf of Mexico provides one potential refuge for coral reefs in the Caribbean.

9D Refuges for corals in time & space
Friday 13 July, 1245, Hall A

Fertility in the fathoms: mesophotic coral reproductive refugia and connectivity

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While shallow coral reefs are threatened around the world, a 'deep reef refugia' hypothesis has recently garnered interest. Mesophotic coral ecosystems (MCEs) between 30-150 m depth are oftentimes less exposed to the synergistic deleterious effects of coastal and global stressors, such as rising sea surface temperatures, acidification and coastal pollution. Due to depth and distance from shore, little is known about the health, ecology and distribution of these environments. In an effort to gauge the refugia potential of MCEs in the US Virgin Islands (USVI) the effects of depth on coral reproductive biology were investigated from 2008-2011. Histological analyses and laboratory observations suggest *Montastraea faveolata* and *Porites astreoides* corals at 35 m are gravid on the same oogenic schedule as their shallow counterparts. Mature *M. faveolata* eggs have been detected to a depth of 44 m. Results from this study are used to parameterize the dispersion of larvae in a biophysical Connectivity Modeling System (CMS) designed to estimate the direction and magnitude of marine larval connectivity. The CMS consists of sub-modules coding for: larval biological and fluid dynamic characteristics; adult production, habitat and settlement cues; and hydrography, temperature and salinity; coupled to a stochastic particle model that tracks the movement of larvae in three dimensions to estimate transport and connectivity over multiple nested scales. The results suggest that USVI MCE coral larval output may be substantial, and that depth may provide a reproductive refuge for imperilled shallow corals. This highlights the critical importance of understanding the scales of coral reef vertical connectivity.

9D Refuges for corals in time & space
Friday 13 July, 1415, Hall A

Ocean acidification refugia of the Florida Reef Tract

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Ocean acidification (OA) is expected to reduce coral calcification, yet we have little understanding of how OA will manifest in dynamic, real-world systems. Natural CO_2 gradients and temporal fluctuations have the potential to both positively and negatively influence the susceptibility of different reef ecosystems to OA. As a first step, there is a need to characterize the natural variability of seawater carbonate chemistry. Since 2009, carbonate chemistry data have been collected bi-monthly for the entire Florida Reef Tract (FRT). CO_2 concentrations and aragonite saturation levels (Ω_{arag}) on inshore patch reefs of the upper Keys can be more favorable for coral calcification than what has been modeled for the tropical surface ocean during preindustrial times ($\Omega_{arag} > 4.3$). Conversely, CO_2 and Ω_{arag} levels on offshore reefs generally represent oceanic carbonate chemistry conditions with present day levels of OA. This gradient is opposite from what has previously been reported for other reef environments. We hypothesize this pattern is caused by: 1) the uptake of CO_2 by photosynthetic seagrasses and algae in the inshore waters of the FRT combined with 2) the influence of Florida Bay waters, which are even more depleted in CO_2 relative to reefal waters during the spring and early summer. These inshore reef habitats are therefore potential acidification refugia that are defined not only in a spatial sense, but also in time; coinciding with the seagrass growing season. Despite this temporal limitation, these seagrass CO_2 sinks may positively influence the resistance of some coral reefs to OA stress.

9D Refuges for corals in time & space
Friday 13 July, 1215, Hall A

Solitons mitigate coral bleaching in the Andaman Sea: the *Porites* perspective

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The symbiosis of tropical corals with unicellular dinoflagellates is very sensitive to thermal stress. Even slightly enhanced temperatures can disrupt the tight association and lead to the expulsion of the zooxanthellae. The Andaman Sea coral reefs experienced an especially extensive bleaching event in 2010. Temperature exceeded the bleaching threshold of 30.1℃ by the end of March with peak values around 32℃ by the end of May extending down to 30m depth. The temperature anomaly caused a complete whitening and high mortality in many of the reefs. However, we found spatial differences in bleaching and recovery related to frequent aperiodic upwelling of cold deep waters entrained by large amplitude internal waves (solitons) likely alleviating the heat stress for the corals. Here, we present data on coral tissue parameters of the massive coral *Porites lutea* collected along the soliton-exposed west and sheltered east sides of the Similan Islands and Andaman Sea. Sampling was completed prior to, during and after the thermal anomaly, and relate bleaching onset to recovery to concomitant temperature recordings indicating soliton impact. Our data indicate that soliton-exposed corals are likely to be more resilient to bleaching than corals from sheltered areas, and indicate soliton-exposed reefs as potential refuges for corals from mass bleaching.

9D Refuges for corals in time & space
Friday 13 July, 1200, Hall A

Vertical connectivity in the Caribbean broadcast spawning coral *Montastraea cavernosa*

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The Deep Reef Refugia hypothesis (DRRH) suggests that deep reefs can act as local recruitment sources for shallow reefs following disturbance. Testing this hypothesis has been difficult, in part due to the scarcity of genetic makers for depth-generalist coral species. To overcome this limitation, 454 sequencing was used to develop new microsatellite loci for 4 Caribbean depth-generalist coral species with diverse life-history reproductive strategies for which there were previously few or no population genetic markers available (*Montastraea cavernosa*, *Porites astreoides*, *Agaricia agaricites* and *Siderastrea siderea*). Eight new microsatellite loci with no significant heterozygote deficiencies were developed for the broadcast spawning coral *M. cavernosa*. These loci were used to assess vertical connectivity between 3 depth zones (<10m, 15-20m and >25m) at sites in Florida, Bermuda and the U.S. Virgin Islands. Overall, findings revealed slight genetic differentiation among populations separated by geographic location, with Florida and the U.S. Virgin Islands more closely related than Bermuda. Conversely, no significant genetic differentiation was found among populations separated by depth. Additional tests of gene flow directionality revealed that rates of larval recruitment from deep to shallow are greater than those from shallow to deep, suggesting significant potential exists for shallow reefs to recover from refugia in deeper water, and supporting the DRRH. These findings highlight the need to re-assess the current level of protection afforded to deep reefs, and inform the design of marine protected areas (MPAs), whose boundaries may follow depth isobaths that exclude significant deep water reef resources.

9D Refuges for corals in time & space
Friday 13 July, 1145, Hall A

Refuges for corals and reefs over the next 100 years

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Refuges from coral reef disturbance are a fundamental aspect of reef ecosystem resistance and resilience and can span many scales in space and time. In the narrowest sense refuges provide resistance either because they are buffered from the disturbance and/or they provide something that ameliorates the disturbance. For example, at small spatio-temporal scales within susceptible habitats colony deep tissue reserves or heterogeneous colony micro-environments provide tissue refuges that resist the disturbance. Or, at larger scales, whole reef habitats may have environmental conditions that avoid the disturbance (e.g. different thermal environment) or conditions that ameliorate the disturbance (e.g. heterotrophic subsidies). In the widest sense refuges increase resilience by promoting recovery of corals and coral reefs. For example, at small scales resilience is fostered because partial, rather than total, colony mortality in susceptible habitats preserves genetic diversity and facilitates vegetative re-growth rather than de novo replacement from external larval sources. At large scales resilience is fostered because populations within the metapopulation are preserved, leading to the possibility of reseeding of susceptible habitats from connected refuges. The properties of an ecosystem, from molecular to habitat diversity, that increase or decrease the refuge effect are not well understood. This presentation provides a theoretical framework to understand the impact of refuges on coral reef trajectories, using high thermal stress disturbance as an example.

9D Refuges for corals in time & space
Friday 13 July, 1130, Hall A

Theme 10. Modelling reef futures

10A Modelling reef futures

Global versus local stressors and the vulnerability of future reefs

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A key challenge for coral reef researchers and managers is the prediction of ecosystem vulnerability as oceans warm and acidify, and as these stressors occur alongside intensified storms and local-scale disturbances such as declining water quality and overfishing. Here, I present projections for how multiple environmental stressors affect reef ecosystem dynamics and how that translates to vulnerability and risk for benthic reef communities. I illustrate the mechanics of stochastic pulse disturbances (e.g. cyclones and bleaching events) and deterministic pressures (e.g. ocean acidification and declining water quality) in driving the dynamics of a simplified reef system between coral and algal-dominated or barren states. I address three key questions. Firstly, under increasing atmospheric concentrations of CO_2, do we expect to see distinct ecosystem thresholds, tipping points or a gradual decline, and how does this projection change with different combinations of local-scale stressors? Secondly, what combinations of global and local/regional-scale factors make reefs the most vulnerable? And lastly, what are the most feasible and effective management and policy options to sustain reef resilience and evade high-risk scenarios in different regions? I attempt to answer these questions through a series of conservative model analyses using the Great Barrier Reef and Indonesian reefs as examples.

10A Modelling reef futures
Monday 9 July, 1545, Hall C

Ghost of bleaching future: seasonal outlooks from NOAA's Operational Climate Forecast System

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Using models to inform the possible future of coral reefs can happen on many scales. NOAA Coral Reef Watch (CRW) and its partners are currently engaged in this work on three timescales. These range from new work with NOAA's National Weather Service, which uses short-term weather forecasts to predict bleaching weather, to work with NOAA's Geophysical Fluid Dynamics Laboratory and academic partners to look at decadal-scale scenarios of coral bleaching, mortality, and ecosystem change. Within these scales, CRW and NOAA's National Center for Environment Prediction recently made a major advance in NOAA's ability to predict thermal stress capable of causing mass coral bleaching: a newly-developed global seasonal outlook system based on NOAA's operational Climate Forecast System (CFS). These outlooks predict the probability of thermal stress events capable of causing large-scale, mass coral bleaching, using a weekly, 28-member ensemble of sea surface temperature fields from the CFS. The new system builds upon the first global seasonal bleaching outlook system, the result of collaboration between CRW and NOAA's Earth System Research Laboratory using a statistical climate model and released at the 11th ICRS. This presentation describes the development and testing of the new CFS-based outlook model, using a series of hindcast simulations, and the performance of the new system during the last year. It also compares performance of the outlooks from the new dynamical-model system and the earlier statistical-model system.

10A Modelling reef futures
Monday 9 July, 1000, Hall C

Effects of rising sea surface temperature and ocean acidification on corals

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Increasing atmospheric CO_2 concentration is considered to change distribution of corals in various ways via global warming and ocean acidification. For example, poleward range expansion of coral habitats is caused by rising sea surface temperature in response to global warming. On the other hand, lower saturation fraction of aragonite due to ocean acidification is presumably prominent with lower sea surface temperatures in higher latitudes. Therefore, the future distribution of coral habitats is considered to be determined by the net effects of global warming and ocean acidification. In this study, using climate model results cited in the IPCC 4th Assessment Report along with simplified indicators for coral habitats, we estimated future potential effects of global warming and ocean acidification on coral distributions in seas close to Japan. The model results suggest that the coral habitats will be

strongly controlled by the poleward range expansion due to rising sea surface temperature and the equatorward range impansion by ocean acidification at the same time. Furthermore, these effects will appear earlier, by the middle of the 21st century, than estimated in previous studies.

10A Modelling reef futures
Monday 9 July, 1200, Hall C

Climate impacts on hydrodynamics and sediment dynamics at reef islands

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Reefs protect the shore of many tropical islands and beaches from waves. Potential impacts of climate change on cyclones, Sea Level Rise (SLR), and coral may reduce fringing and barrier reefs role as protection. Increased storminess generates larger waves, and SLR creates deeper water over reefs and lagoons, allowing larger waves and possibly at different direction to that of the locally generated waves to reach the shore. This leads to a potential significant change of magnitude and direction in wave energy flux at the shore and beach erosion. This paper models the impacts of selected aspects of climate change on a sand-cay shoreline within a platform reef under two plausible scenarios. Firstly, if coral growth does not keep pace with SLR; secondly, if corals die due to ocean warming and acidification. In the former scenario, reefs may survive but the islands they shelter maybe destroyed or significantly degraded. In the second scenario, both reefs and shoreline will suffer, but coral death elevates the level of bio-eroded sediment supplied to the system and this may partly buffer the impact of SLR on beach erosion. To address these objectives, a shallow water wave is setup to access the reef hydrodynamics and run-up under the different scenarios explained above. This model is calibrated against field measurements. The wave model is used to drive an equilibrium-state shoreline parametric model for reef-islands, which is used to assess the response of the reef-island system to changes in relative crest level and sediment production.

10A Modelling reef futures
Monday 9 July, 1230, Hall C

The effects of sea-level rise on reef-flat food webs

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The effects of sea-level rise are typically considered in coastal habitat types, such as seagrass beds and mangroves. However, extensive Pacific reef flats are also particularly susceptible to changing sea level because they are adapted to functioning in very shallow water. Reef flats are often highly tidal, and water depths of <50 cm at low tide lead to profound changes in reef fish assemblages because of the migration into deeper habitats of larger species that are present at high tide. Here we investigate the functioning of reef-flat food webs over a tidal cycle by parameterising Ecopath models at both low and high tide with site-specific data from two locations (close to shore and close to the reef crest) on the reef flat at Heron Island, Great Barrier Reef. By focusing the models on changes in fish communities with natural fluctuations in water depth, we demonstrate the significant spatial and temporal changes in food web dynamics over tidal cycles and with position in the reef-flat seascape. Future sea-level rise will lead to greater water depths at low tide, fewer changes in fish assemblages with tidal state, and less temporal variation in food webs. Consequently, we use our food web models to provide the first insights in 'permanent high tide' on the food webs and fishing of reef flats. These findings expand our ability to predict the effects of sea-level rise on reefs, and provide a novel example of how sea-level rise will affect reef fishes.

10A Modelling reef futures
Monday 9 July, 1145, Hall C

Quantifying risk to tropical reefs ('QUARTR')

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Understanding the risk of coral reef collapse and the likelihood of recovery worldwide is important for both the short-to-medium term management of tourism and fisheries, as well as the long-term management of biodiversity and protection of local economies. To do this computer models capable of representing how reef organisms interact, both between themselves (competition) as well as with the environment are required. Previous modelling work assessing the implications of climate change for future reef distributions has tended towards one of two end-member approaches: (1) reef-scale models that consider the properties of specific species resolved at fine scales, and (2) regional to global-scale models that may not represent biology or ecosystem dynamics at all. No current model bridges the ecological-scale gap and resolves ecosystem dynamics at a global scale. To address this, the

QUARTR project will involve the construction of a 'functional type' ecosystem model combining approaches from marine plankton ecology with established terrestrial ecosystem modelling concepts; application to tropical reefs, sits somewhere in between but is a closer analogue to terrestrial ecosystems in which species have more comparable generation times and dispersal constraints together with a fixed 'location'. The overall project deliverable will be maps of reef systems most at risk with a probabilistic measure of the likelihood collapse as well as time to recovery.

10A Modelling reef futures
P102

Maintenance of positive carbonate budgets requires local and global action

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Coral reef framework displays substantial architectural complexity, which is positively associated with high levels of biodiversity and other ecosystem services. Framework complexity is maintained by a balance between carbonate accretionary (e.g., calcifier production) and erosional forces acting at the reef surface (e.g., grazers, hurricane damage) and internally (e.g., micro- and macroborers). Ecosystem changes, both in the recent past (e.g., loss of *Diadema*, depleted coral cover) and future (e.g., ocean acidification, temperature change) may disrupt this balance. This can result in a negative carbonate budget, where erosion exceeds accretion and important reef structure is lost. Recent evidence, showing that reefs across the Caribbean are losing rugosity, supports this. Here we model the carbonate budget of a Caribbean reef, and assess the impacts of ecosystem change on the reef framework. We demonstrate that Caribbean reefs have been influenced by recent past events occurring on ecological timescales. We identify the factors important in driving reef budgets, and highlight how they have changed over the past fifty years, with bioerosion-associated factors now playing a more important role in determining budgetary state. We then use the latest climate forecasts to drive our model into the future, using 'business as usual' and 'best case' scenarios to explore the impact of mitigating global greenhouse gas emissions and taking local conservation action on future Caribbean reef budgets. We find that both local and global action is needed to achieve a positive carbonate budget which has important consequences for policy.

10A Modelling reef futures
Monday 9 July, 1245, Hall C

Analysis of coral reef resilience: a generic modelling tool

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Coral reefs, highly diverse but also fragile ecosystems, are increasingly threatened. From all over the world numerous reports indicate phase shifts from coral dominated systems to algal dominance. While the consequences are similar, the causes and involved processes are diverse, depending on the local species composition and impacting factors. Hence, there is an urgent need to better understand key processes and to identify drivers in local situations. Here we present a generic, spatially explicit, individual-based model in which competition drives the dynamics of a virtual benthic reef community, comprising scleractinian corals and algae, under different environmental settings. Virtual organisms are constrained by environmental factors and strictly interact with their direct neighbours with actor specific responses. Higher system properties, like population dynamics or community composition arise through self-organisation as emergent properties. Simulation results for Zanzibar reveal that community dynamics can vary to a high degree over time even though key parameters are kept constant. Although the overall coral coverage stays relatively stable, the cover for single species can fluctuate strongly. Furthermore, we determine specific alterations of dominance patterns within the coral community and specific extinction risks for various environmental settings. This tool integrates current knowledge on coral reef functioning and provides the possibility to adjust for specific local or regional conditions with rather little effort. Future model application will include the analysis of different coral reef regions worldwide, to identify local drivers of reef resilience which will then allow to evaluate the implications of different management regimes.

10A Modelling reef futures
Monday 9 July, 1115, Hall C

Anthropogenic aerosol emissions drive variations in Caribbean coral growth

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Coral growth rates are highly dependent on forecastable environmental variables such as sea surface temperatures and solar irradiance potentially permitting projections of future climate impacts. Multi-decadal variability in coral growth rates has been documented throughout the Caribbean for the last 150-200 years. Recent global climate model evidence strongly suggests that multi-decadal variability in sea surface temperatures of the North Atlantic and Caribbean is a probable consequence of external aerosol forcing. Here we show that aerosol driven sea surface temperature and solar irradiance outputs from an Earth System model can predict multi-decadal growth oscillations in some Caribbean coral reefs. Ensemble projections for a range of emission scenarios show that aerosols can decouple future relationships between radiative forcing and Caribbean coral growth. Our findings indicate the key driver of multi-decadal coral growth rates in the Caribbean to date, is not ocean acidification or climate change due to greenhouse gases, but regional climate change due to anthropogenic aerosols. Our projections provide an improved baseline against which the effect of other anthropogenic and climatic stressors can be assessed.

10A Modelling reef futures
Monday 9 July, 1515, Hall C

Physiologically relevant bleaching threshold methods provide updated global coral bleaching projections

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Climate warming threatens to increase the frequency of mass coral bleaching events. Using future sea surface warming scenarios from global coupled climate models, previous studies have estimated that corals will experience biannual bleaching events by mid-century unless they are able to acclimatize or adapt at a rate of ~0.2-1.0°C per decade. Recent evidence shows that corals have a variety of mechanisms by which they can respond to changes in their thermal environment; for example, prior experience to elevated temperatures has been shown to increase the thermal tolerance of corals both in the field and the laboratory. Whether the magnitude of such responses will match the projected increases in sea surface temperatures is still unknown. Building on previous modeling work and recent studies on the physiology of coral bleaching, we develop several bleaching thresholds, each based on an alternative underlying mechanisms for acclimatization or adaptation. We use global SST output from NOAA/GFDL Earth System Models to evaluate the new emissions scenarios for the 5th IPCC Assessment on coral bleaching trajectories. Results provide a range of future bleaching frequencies under different emissions scenarios using the revised bleaching thresholds. Model results are validated by comparing historical bleaching observations in well-documented areas (e.g., Great Barrier Reef, Caribbean, E. Africa). Improved bleaching thresholds will refine future bleaching projections, advance population and community models that rely on an accurate bleaching predictions, and provide better real-time bleaching alerts to coral reef managers.

10A Modelling reef futures
Monday 9 July, 1530, Hall C

Climate change vulnerability maps for coral reefs in Micronesia

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Mapping vulnerability to climate change is a critical conservation priority since there is increasing evidence that there will be great spatial variability in the severity of climate change impacts on coral reefs. We are developing and implementing an approach to map the vulnerability of reef sites in Palau and the Mariana Islands to bleaching based on: historical summertime temperature variability (shown to increase bleaching resistance), local knowledge of coral community composition, and statistical downscaling of the projected rates of SST change from the climate model ensemble shown to be most accurate for the west Pacific. Preliminary analyses suggest that the spatial variability in vulnerability is sufficient to inform management decision-making in both archipelagos. Managers in these areas should prioritize the protection of low vulnerability sites (e.g., areas with high temperature variability relative to other sites in the area, high

percentages of bleaching-resistant coral species, and low projected frequencies of bleaching threshold exceedance). We demonstrate that under a fossil-fuel intensive emissions scenario (A2), there is a 20-25-year range across the Pacific in the year in which the model suggests that bleaching thresholds will be exceeded annually. The vulnerability maps include an assessment of uncertainty to ensure that decisions are made transparently, based on the best available science, and in a timeframe necessary to buy reefs time.

10A Modelling reef futures
Monday 9 July, 1030, Hall C

Modelling tropical cyclone impacts on the world's coral reefs

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Coral reefs are under threat from a range of interacting stressors predicted to increase in severity and frequency over time. Modelling reef futures thus requires understanding the relative timing and frequency of key stressors that combine with routine processes to shape reef form and function. Global databases that establish the basis for this understanding have recently been published for some key stressors (bleaching, human impacts). However, no such data exists for tropical cyclones (TCs), which can have both negative (wave damage) and positive ('cool wakes' of lowered sea surface temperatures that relieve thermal stress) impacts on reefs. Yet identifying the likelihood that reefs will be frequently versus rarely exposed to wave damage, and frequently cooled at times of thermal stress, is essential to prioritize reefs for conservation. To address this, we developed global (40°N-40°S) databases of the timing and frequency of TC-induced: 1) probable wave damage (using meteorological models, TC observations, field surveys reef wave damage) and 2) sea surface cooling (using satellite sea surface temperature and thermal stress data) over the recent past (1985-2010). We then compared the spatial extent of wave damage versus cooling to identify whether each TC resulted in a net benefit or cost to reefs. From these data it is apparent that while the frequency of reef exposure to TC impacts is highly variable, net benefits are possible and more likely to occur in some regions than others, potentially providing refugia for reefs in future.

10A Modelling reef futures
Monday 9 July, 1015, Hall C

Implementing the end-to-end ecosystem model Atlantis on the Great Barrier Reef

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Whole of ecosystem models that incorporate a broad range of physical, chemical and biological processes are well suited to exploring the dynamics of the complex issues related to multiple human uses in coastal regions, including cumulative effects. Over the last decade there has been strong growth in these kinds of models and they are now sufficiently mature to be applied to exploring potential system impacts, identifying useful monitoring methods and evaluating alternative management strategies. Amongst them, the simulation modeling approach 'Atlantis' successfully integrates physical, chemical, ecological, and anthropogenic processes in a three-dimensional, spatially explicit domain. This model is now being implemented for the Great Barrier Reef region, using existing data (oceanography, biogeochemistry, habitats, species distributions and abundances, trophic links, and anthropogenic pressures and activities) to generate a baseline historical hindcast and identify key model uncertainties. Preliminary results will be presented, and further improvements and potential applications in terms of management strategy evaluation will be discussed.

10A Modelling reef futures
Monday 9 July, 1500, Hall C

Seasonal dynamical prediction of coral bleaching risk for reef management

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Seasonal forecasts from dynamical ocean-atmosphere models of high risk conditions in marine ecosystems can be very useful tools for managers, enabling proactive management responses. Real-time forecasts for coral bleaching risk on the Great Barrier Reef (GBR) are currently produced operationally using the Bureau of Meteorology's seasonal prediction system POAMA. These forecasts provide an early warning of potential bleaching risk prior to summer, which allows reef managers to both focus monitoring programs and implement strategies to minimise bleaching damage, as well as brief government. Experimental seasonal forecast products for bleaching risk are also under development for the Western Pacific as a part of the Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP). These products are

intended to support the development of a range of adaptive and management activities to improve reef management in the Western Pacific. Under climate change, it is expected that the frequency and severity of bleaching will increase on the world's coral reefs, and thus an improved understanding and management of these sensitive ecosystems is imperative.

10A Modelling reef futures
Monday 9 July, 1215, Hall C

Predicting Caribbean coral reef futures using IPCC AR5 models

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Future coral bleaching and subsequent mortality can be projected using sea surface temperature (SST) data derived from global, coupled ocean-atmosphere general circulation models (GCMs). Here an effort is presented that refines most previous efforts in three important ways. First, a newer generation of GCMs included in the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report are used. While these models faithfully capture many aspects of climate, they vary in their skill representing such features as the tropical ocean seasonal cycle and El Niño Southern Oscillation (ENSO) variability. Such weaknesses reduce the accuracy of predictions of bleaching. The second refinement is that the GCMs used, are corrected for their annual cycle end ENSO variability. Subsequent thermal stress is calculated in degree heating weeks and is compared to previously published thresholds for Caribbean reefs. A third refinement is made by including species specific bleaching thresholds. Species specific thresholds were derived from experimental studies in which Caribbean corals were subjected to thermal stress. By using these thresholds and known species composition the evolution of reef composition is modeled for different emission scenarios. As an example, results are presented for Little Cayman, Cayman Islands.

10A Modelling reef futures
Monday 9 July, 1130, Hall C

Theme 11. Ecological dynamics, resilience & phase shifts

11A Ecology & macroecology

How are reef fish packed? The influence of regional richness

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Great advances have been made on the relationships between alpha and gamma diversity for sessile reef-building corals. However, relatively little is known regarding such relationships for reef fish (mobile animals) communities. We addressed this gap compiling one the most biogeographically comprehensive reef fish community datasets - visual censuses through area-standardized strip transects (20 x 2 m = 40 m^2) between 0 and 30 m deep in tropical rocky and coral reef systems (n = 5.916 transects). The geographical range encompassed 103 sites spread through 17 major localities embedded in 6 main tropical biogeographical provinces: Caribbean, SW Atlantic, Tropical Eastern Atlantic, and Pacific and South Pacific. Moreover, in addition to the classical taxonomic multi-scale approach (transect-site, site-locality, locality-region) we also present a functional richness packing perspective - functional groups per unit area. Local vs. regional plots, both taxonomic and functional, show that local community is positively enriched as regional richness increases, with no sign of approaching a saturation level. This indicates a strong influence of regional processes on the local composition of communities. Up-scaling analyses indicate that as one moves to richer biogeographic regions beta-diversity becomes increasingly important. We have also observed, on a global basis, an increase of both taxonomic and functional packing upon increasing coral regional richness. These results may indicate that diversity begets diversity in terms of habitat heterogeneity (i.e. niche diversification); however, both coral and fish evolution may have been driven by common factors. We show the importance of multi-scale and cross-ocean macroecological analyses for the understanding of processes underpinning local biodiversity functioning.

11A Ecology & macroecology
Tuesday 10 July, 1630, Hall D

Heterospecific aggression and dominance among butterflyfishes

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Aggression between species is a common, direct interaction observed in many different animal communities. Studies that distinguish traits (aggression) from interactions (interference), as well as causes from consequences, are needed for a greater understanding of the ecology and evolution of heterospecific aggression, and in particular, for determining any role in species coexistence. Moreover, rigorous, quantitative approaches to determining heterospecific dominance hierarchies, and assessing the ecological correlates of dominance are required to advance our understanding of heterospecific aggression and its implications for biodiversity maintenance. Aggression between corallivorous butterflyfish has been associated with territoriality and linked with the availability of preferred prey, but dominance and its ecological correlates remain to be quantified. Here, we examine aggression between butterflyfish, quantify the dominance hierarchy and examine dietary specialisation as a correlate of dominance. Observations of encounters between butterflyfishes were scored on a categorical scale of interaction strength; and dominance quantified using a model based on a matrix of pair-wise encounters. We also fitted models in which dominance was modelled as an explicit function of dietary overlap and specialisation. We find that the probability of a heterospecific encounter escalating to aggression is a strongly increasing function of dietary overlap. Further, dominance increases with increasing dietary specialisation, suggesting that highly specialised species are the most aggressive and the least likely to flee an encounter. These findings indicate that the spatial distribution of preferred prey is likely to be an important determinant of both the evolutionary drivers, and the ecological consequences, of aggression between butterflyfish species.

11A Ecology & macroecology
Tuesday 10 July, 1530, Hall D

Stability of protected Bêche-de-mer populations, inferences on Curryfish fishery sustainability

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Sea cucumbers are commercially harvested on the Great Barrier Reef (GBR) by the Queensland Bêche-de-mer (BDM) Fishery and the curryfish, *Stichopus herrmanni* is a key species. Currently there are no data on the population biology of *S. herrmanni* on the GBR despite its ecological importance to local reef health and the vulnerability of sea cucumber populations to recruitment over fishing. We documented the population structure and assessed recruitment in *S. herrmanni* at One Tree Reef (OTR), a no-take protected area in the GBR Marine Park. Size distribution and density of *S. herrmanni* populations were determined at several sites including a temporal component by re-surveying two of these populations over the two years of the study (2009-2011). The density and the size distribution of *S. herrmanni* did not change over two years indicating stable population metrics. There was a spatial separation of populations differing in size and density. Mean length of individuals in adjacent pie-crust/coralline algal and lagoon reef wall habitats was 272 mm and 346 mm, respectively in both survey years. Individuals in reef rim habitat were larger (mean 365 mm) and those in outer and deeper reef slope habitat (mean 397 mm). This species exhibited affinity to reef features with 80-100% of individuals near lagoon reef features. We addressed hypotheses on potential drivers of population structure: (1) adult migration and (2) phenotypic plasticity in growth with respect to habitat condition. While connectivity through adult migration may occur, the size structure and location of some populations indicated that adult size is determined by post recruitment habitat mediated growth. This likely determines terminal growth of *S. herrmanni*. The size limit for *S. herrmanni* in the GBR BDM fishery (35 cm length) would make it legal to remove 2% of the population in the pie crust site, 53% of the population the lagoon reef habitat and 85% of the population on the reef slope. So while some smaller individuals in shallow habitats may be protected, populations of *S. herrmanni* in deeper habitats may be nearly entirely removed. This suggests that the current harvest is very likely to be in the range of inappropriate levels. As coral associated BDM species such as *S. herrmanni* provide significant levels of nutrients to support coral growth and pH buffering (Schneider *et al.* 2012), contributing to reef resilience, the sustainability of the GBR BDM fishery for this and other species should be revisited.

11A Ecology & macroecology
P103

Local aggregation and regional biodiversity maintenance on coral reefs

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Understanding patterns of commonness, rarity, and biodiversity in nature has been one of community ecology's core aims since its inception. Recently, models of community dynamics, which are frequently divided into 'niche' and 'neutral' models, have been analyzed to generate predictions about species-abundance patterns. Such models often assume that species abundance data are a random sample from the regional community, but real communities' exhibit high levels of local-scale aggregation. In this presentation, we first show how and why gamma and lognormal distributions provide excellent approximations for a wide range of neutral and non-neutral models, respectively. Then, we extend these models to incorporate distorting effects of local aggregation, and we apply these models to analyze patterns of commonness and rarity in Indo-Pacific corals and reef fishes. Results show that, when local aggregation is allowed for, neutral and non-neutral models make indistinguishable predictions about patterns of local commonness and rarity in corals and reef fishes. However, the models make implicit predictions of the size of the regional species pool that differ dramatically. The non-neutral lognormal distribution predicts regional species richnesses that are highly consistent with non-parametric estimates. In contrast, the neutral approximation predicts species richnesses that frequently exceed the fauna's global diversity by several orders of magnitude. Our results confirm that poor fit of neutral models in earlier analyses is not an artifact of local aggregation, but real evidence that non-neutral dynamics drive commonness and rarity on coral reefs.

11A Ecology & macroecology
Tuesday 10 July, 1500, Hall D

A sponge loop in coral reefs: energy recycling in benthic ecosystems?

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For decades a major question in coral reef ecology, known as 'Darwin's Paradox', was: How can one of the most productive ecosystems in the world thrive in the marine equivalent of a desert? Sponges play a pivotal role in answering this question. Recent findings

indicate that sponges are primary consumers of dissolved organic matter (DOM), the largest energy source present and produced on reefs. Their newly found, unique, and fast cell turnover provides a key to understanding how energy is transferred and retained within the coral reef ecosystem. Sponges convert energy into rapidly proliferating filter cells that are subsequently shed into the ambient water, leading to the funnelling of energy into local communities as opposed to the expected dispersion and loss of dissolved food. In open oceans bacteria mediate the recycling of dissolved energy through the well-established 'microbial loop'. For benthic ecosystems our understanding of the dominant pathway of DOM cycling needs reconsideration. Transformation of DOM into detritus by a high turnover of sponge cells may be the major pathway of DOM cycling on coral reefs. While settling, expelled cellular particles are subject to bacterial degradation, regenerating inorganic nutrients, and are intercepted by particle feeding communities, like detritivores. These small creatures are fed upon by larger organisms up to the top of the food chain, ultimately 'looping' energy back into the ecosystem. The hypothesized 'sponge loop' may be a complementary recycling pathway in benthic ecosystems, such as coral reefs. This new biological loop facilitates the formation of hotspots of biological activity.

11A Ecology & macroecology
Wednesday 11 July, 1430, Hall D

Macroecological relationships between reef-coral species' traits and geographic range size

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Reef-building corals display a wide array of geographical range sizes, which vary by up to four orders of magnitude on a global scale and up to two orders on the Great Barrier Reef. These differences in range size are both latitudinal and longitudinal. Understanding the life history traits that cause such differences is a major goal of biogeography. Here, we explore relationships and patterns among species-level macroecological traits and range sizes, to identify those traits most closely associated with endemic or pandemic distributions. Traits included local abundance, resource use (generalist vs. specialist), reproductive mode, type of larval development, larval nutrition, and evolutionary species age, among other morphological and environmental variables. Very few individual traits were associated with range size, however, coral assemblages from isolated locations in the Indo-Pacific have an overabundance of species with both small eggs and autotrophic propagules. We conclude that linking multiple traits results in a more powerful predictive capability than when traits are analysed separately.

11A Ecology & macroecology
Tuesday 10 July, 1740, Hall D

Second order ecological implications of climate change for coral communities

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Direct detrimental consequences of increased frequency of heatwaves, more severe cyclones and reduced calcification have been speculated upon in the coral reef - climate change literature for over a decade. Whereas effects on individual coral colonies (viz. density; linear extension rates) have received much attention, there has been much less analysis on likely effects on coral populations (survivorship) and communities. Here, with a focus on coral populations and communities, I examine interrelationships among several key variables being affected by warming seas and reduced calcification rates: linear extension and density of individual corals; return intervals for heatwaves and destructive waves; intervals between outbreaks of crown-of-thorns starfish (COTS). Drawing on studies of geographic variability in coral community recovery following cyclones and COTS impacts, I investigate effects of reduced performance (individual and population growth) on the time taken for recovering coral populations to reach key size, and percent cover thresholds of vulnerability to waves and COTS. 'Recoverability' site attributes (viz. propagule supply and survival schedules) appear to vary systematically according to the geographic disposition of the meta-community in which the reef is located, and the site's location on the reef (reef flat or slope, shallow or deep, wave-exposed or sheltered).

11A Ecology & macroecology
Wednesday 11 July, 1015, Hall D

Specificity in coral-*Symbiodinium* interactions and the resilience of reefs

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All reef-building corals in the order Scleractinia depend on endosymbiotic algae in the genus *Symbiodinium* for nutrition and survival. Significant levels of taxonomic diversity in both partners results in numerous coral-

Symbiodinium interactions, with unique functional characteristics. To understand how community resilience is related to interaction patterns, we created and analyzed the first coral-*Symbiodinium* networks utilizing a global dataset of 18 years of interaction records from corals and *Symbiodinium*. Our results reveal that the majority of coral and *Symbiodinium* species are specialists and the specificity of a coral's symbionts is predicted by symbiont transmission mode. Importantly, the relative abundance of corals with different transmission modes alters reef-level interaction patterns of connectance and nestedness, likely modifying the resilience of coral-*Symbiodinium* communities. Our results suggest further network analyses will assist coral reef conservation efforts by identifying resilient species or reefs.

11A Ecology & macroecology
Wednesday 11 July, 1530, Hall D

Effect of reef structural complexity on parrotfish grazing spatial distribution

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Grazing is an important ecological process; it influences macroalgal dynamics and structures the benthic community of coral reefs. In many Caribbean reefs parrotfish are the key grazers, yet we do not fully understand how reef structural complexity may influence their grazing. In this study we investigated the effect of reef complexity on grazing spatial distribution of the two most common species of Caribbean parrotfish, *Sparisoma viride* and *Scarus iseri*. We first divided each territory of three *S. viride* and five *S. iseri* individuals into 2 x 2 m cells, and mapped the benthos in each cell, measuring the size of every feature that was larger than 10 cm in diameter. We then recorded the grazing rate of each fish over a week by direct observation and through unsupervised video cameras. We calculated reef complexity as the surface area of each cell and compared it against grazing intensity. The spatial distribution of grazing of both fish species was significantly correlated with complexity, however this correlation was different for each species. *S. viride* preferred grazing in reefs with low to medium complexity, its grazing increased from very low to mid-low reef complexity and then slowly decreased. *S. iseri* preferred flatter reefs, with a negative relationship between the grazing intensity of *S. iseri* and reef complexity. These results highlight the importance of reef complexity in determining ecological processes. Grazing was better correlated to reef complexity than to coral cover, and re-emphasises the importance of measuring complexity when investigating aspects of grazing.

11A Ecology & macroecology
Tuesday 10 July, 1730, Hall D

Positive within-mat feedback facilitated both Cladophora blooms and associated macroalgae

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Persistent algal blooms have been documented on reefs worldwide, including the Eastern Tropical Pacific (ETP). Two key questions are how blooms persist in low nutrient / high herbivory environments, and how they affect associate algae. For ~10 yrs, dense and thick *Cladophora* spp. mats have expanded on an ETP reef, dominating from the reef base (~4 m) to >20m. We asked: 1) what are the roles of herbivory and nutrients in sustaining these mats, and 2) how do mats affect growth and consumption of associate algae. Both within the mat and on the adjacent reef slope, we varied nutrients and herbivory on transplanted *Cladophora*. Herbivory reduced biomass, though rates were higher on the reef than within the mat. Further, addition of nutrients greatly decreased herbivory rates (~40%) in both sites. We assessed the effects of *Cladophora* on the palatable associate alga, *Acanthophora spicifera*, by varying the presence of *Cladophora* and herbivory within the mat and on the reef slope. Growth of *Acanthophora* was greater within the existing mat and highest when *Cladophora* was directly associated. Though overall growth on the reef was slower, growth of *Acanthophora* was also enhanced within *Cladophora* mats transplanted to the reef. Herbivores only grazed *Acanthophora* on the reef and without *Cladophora*; all other treatments were afforded protection by *Cladophora*, even those in cleared areas of existing mats. Thus, *Cladophora* blooms persisted through resistance to herbivory strengthened by nutrient enrichment; further, mats facilitated associated species through herbivory reduction and enhanced growth, likely through nutrient transfer.

11A Ecology & macroecology
Wednesday 11 July, 1400, Hall D

Species distribution models for macroecological studies of Hawaiian corals

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Coral species exhibit differential responses to biological and environmental factors that influence their range and distribution. Predictive species distribution modeling is an approach to construct maps of coral distributions at macroecological scales that utilizes field observations and environmental covariate layers. Using this approach, we examined the distribution of dominant scleractinian species for the Hawaiian Islands. Data compilation yielded over 15,000 geo-referenced coral survey samples for the four most common coral species (*Porites compressa*, *Porites lobata*, *Montipora capitata*, and *Pocillopora meandrina*) and 6 spatially-explicit environmental datasets including wave heights, temperature, depth, bottom aspect, slope, and rugosity. Data were standardized to high resolution spatial grids and species observations were made binary (presence/absence). Model runs were performed with a suite of regression and machine learning methods. Coral probabilities of occurrence were driven primarily by depth and maximum significant wave height. Model performance, evaluated by receiver operating characteristic area under curve and the kappa statistic, indicated very good agreement between model construction and validation data sets. The boulder coral *Porites lobata* and *P. meandrina* were predicted to occur on exposed coastlines with high wave energies (north, west, and south) within shallow to moderate fore reef depths (6-20m). Wave variables were stronger predictors for the *Porites compressa* than the other three coral species which may reflect the greater vulnerability of the branching morphology to physical disturbance. These spatially-explicit coral species maps are vital for studies of population dynamics, climate change impacts, and marine spatial planning.

11A Ecology & macroecology
Tuesday 10 July, 1745, Hall D

Contributions of octopuses to reef structure

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Middens of *Octopus vulgaris* were marked and followed for 6 years on the Plantation Beach reef at Cayos Cochinos, Honduras to determine what role, if any, they played in reef structure. Macroinvertebrates such as octopuses and hermit crabs are integral parts of coral reef systems. Octopuses range widely over reefs feeding on a variety of organisms. They create dens and middens within the reef, acting as environmental engineers providing resources such as shelters for other organisms. Hermit crabs are attracted to middens where they may feed and/or obtain a gastropod shell. Other crustaceans, such as stomatopods, are also attracted to middens, placing burrows around the perimeter or within the growing middens. These crustaceans also prey on organisms attracted to the middens, contributing items such as shells from molluscs and hermit crabs to the middens. As octopus dens are abandoned, the middens can become incorporated into the reef structure when encrusting organisms such as poriferans, cnidarians, and algae cover the midden remains. After 3 years, none of the middens marked in year 1 were distinguishable; they were wholly incorporated into the reef structure. Four den sites were occupied for each of the 6 years. Middens for these sites were not cumulative. Sites were further engineered by occupants and through what appeared to be environmental influences such as storms bringing large debris to the area. Wave action likely buried middens and moved shells in more exposed areas. This research was made possible through the permission of DIGEPESCA and the Honduran government.

11A Ecology & macroecology
P104

Structure and spatial distribution of coral plain communities in the Gulf of Uraba, Colombia

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This study shows the results of the characterization and ecological analysis of coral plain communities in the Gulf of Uraba in the Colombian Caribbean during the second semester of 2009. Two fringing reefs were found, with two strata defined and classified as ecological units by Geister (1983) and Diaz *et al.* (2000). The first, shallow reef plains, are dominated by *Siderastrea siderea*, and the second complex are characterized by soft slope reef terraces of *Agaricia tenuifolia* and mixed corals. The structure of the reef was evaluated in four samples by coverage estimation, using the point intercept technique (Ramirez, 2006). We did similarity analysis of normal and inverse classification with Bray-Curtis and Morisita indices, and also applied Shannon-Wiener and Simpson indices. We assessed the status of the reef with ecological indices of reef health, proposed by Ramírez (1985). The analysis showed that reefs are dominated by live coverage of 67% *Siderastrea siderea*, followed by *Millepora complanata* (20%), and *Porites porites* (8%). Other species were present but their relative coverage was less than 4%. A high percentage of dead coral substrates with high vegetative development were found. The classification analysis showed homogeneity in the ecosystem in terms of species composition, and differences in their

distributionas a result of the tolerance and resilience of certain species to specific environmental terms. The factors of degradation were found to be: waves, sedimentation from the Atrato river and 4 streams into the bay, as well as anchor damage and coral diseases.

11A Ecology & macroecology
P105

Primary producer influences on element cycles and microbial ecology in reef environments

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Coral reef associated benthic primary producers have been described as altering biogeochemical cycling and microbial processes in their own ecosystems. In order to quantify these influences, a series of studies in the backreef system of Moorea, French Polynesia have been conducted. Rates of photosynthesis, respiration, and dissolved organic carbon (DOC) release were assessed for dominant benthic primary producers, including calcifying and non-calcifying macro-algae, turf-algae and corals. Subsequently, planktonic and, for representative organisms, also benthic microbial community response to these dissolved exudates were examined. Microbial community responses were assessed by measuring bacterial growth rates, oxygen and DOC fluxes in 48 h incubation experiments. Results show that all investigated algae exuded significant amounts of DOC into their surrounding environment. High photosynthetic performance was generally coupled with high DOC release and concomitant high bacterioplankton growth yields. Results further revealed that the planktonic microbial community in this backreef ecosystem was generally net-heterotrophic and this heterotrophic character was additionally stimulated by algal exudates. In contrast, the benthic microbial community living in calcareous reef sands showed strong autotrophic character, and the autotrophic metabolism of the microphytobenthos was enhanced by dissolved coral exudates. This shows the variability of benthic primary producer influences in different ecosystematic compartments. It indicates their differences on planktonic and benthic microbial ecology and key environmental parameters, and highlights implications for oxygen availability during shifts from coral to algae dominance. Finally, this study provides the first data of diurnally resolved, primary producer induced changes in cycles of matter, in both benthic and planktonic reef environments.

11A Ecology & macroecology
Wednesday 11 July, 1245, Hall D

Benthic succession following coral bleaching and disease at Palmyra Atoll

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Disturbance events, such as disease outbreaks on coral reefs, provide a unique opportunity to study successional trajectories across ecosystems and disturbance regimes. In 2009 a bleaching event occurred at Palmyra Atoll, a remote, near-pristine central Pacific reef. By February 2010, a subset of permanently monitored *Acropora cytherea* colonies developed an acute tissue-loss disease consistent with field and histological signs of *Acropora* white syndrome. To understand the trajectory of early stages of coral reef succession following a disturbance, we analyzed the benthic community development from three regions on these colonies: 1) newly bare skeleton bordering diseased tissue, 2) dead skeleton 5 cm from the diseased tissue, and 3) dead skeleton 15 cm from the diseased tissue. We measured algal species and functional group diversity, percent cover, and canopy height. New substrates consistently had the lowest total percent cover of different algal groups, and crustose coralline algae (CCA) covered the largest proportion of older substrates. Further, species composition and canopy height were different across sample regions, indicating that each region represented a distinct successional stage. Following disturbances on many reefs, fleshy algae tend to dominate newly-exposed substrates. In contrast, CCA, an important facilitator for coral recruitment, quickly establishes at Palmyra where there are few local human impacts. Studying ecological succession following disturbances on functionally intact coral reefs improves both our understanding of reef resilience in the absence of direct anthropogenic impacts, and our ability to manage impacted reefs for increased resilience.

11A Ecology & macroecology
Wednesday 11 July, 1030, Hall D

Optical indices for coral pigments and reef community light-use efficiency

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Photosynthetic pigments determine the optical absorbing and reflecting characteristics of

corals and other reef plants. Passive, non-invasive measurements of spectral absorptance (=1-reflectance) can be inverted to provide information about the identities and concentrations of pigments within a plant. Light-use efficiency (LUE) for photosynthesis is also largely driven by plant pigmentation and thus also amenable to measurement by spectral absorptance. Finally, reef community calcification is strongly correlated with productivity, which suggests the possibility of defining an optically measurable LUE for calcification. This paper presents results of mesocosm measurements of coral colony and reef community LUE for photosynthesis and calcification, with coupled measurements of spectral absorptance. As expected, the LUEs vary both with experimental subject (i.e., individual corals or reef community-types) and with changing environmental conditions (ambient light, water temperature, water chemistry). Spectral absorptance varies in kind. The implication is that optical measurements can quantitatively characterize the biogeochemical status of reef plants and communities, potentially affording a novel means for investigation of reef ecosystem function.

11A Ecology & macroecology
Tuesday 10 July, 1700, Hall D

Top-down versus bottom-up: who's controlling Red Sea coral reef functioning?

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Overfishing and eutrophication have been shown to lead to a reduction in herbivory and an increase in algal growth, and are among the most significant local pressures to coral reefs. Here, we investigated the contribution of eutrophication and overfishing on coral reef functioning in the Central Red Sea. More specifically, we evaluated the independent and combined effects of the top-down factor herbivory and the bottom-up factor inorganic nutrient availability, on changes in condition and metabolism of corals, algae, and associated microbes. We deployed exclosure cages and fertilizer sources over 4 months (5 temporal samplings) to study changes in metabolism of *Acropora squarrosa*, and in epibiotic cover on terracotta tiles. First findings indicate that simulated eutrophication alone had no impact on algae biomass production. However, when herbivores were excluded, biomass increased 40 times. Algal respiration was only significantly altered by the combination of simulated overfishing and eutrophication. By contrast, neither coral respiration nor settlement of invertebrates was significantly affected by any treatment (or combination thereof). Responses to changed conditions of coral-specific parameters (biomasses and their isotopic signatures, zooxanthellae densities and diversities, chlorophyll contents, and characteristics of microbial assemblages), as well as algae-specific parameters (biomasses and their isotopic signatures, and chlorophyll contents) to environmental settings (e.g. dissolved and particulate organic matter and inorganic nutrient availability) are discussed. Understanding drivers of reef functioning in the Red Sea are important in order to elucidate the impact of anthropogenic actions.

11A Ecology & macroecology
Wednesday 11 July, 1515, Hall D

Relative contributions of environmental factors to the subtidal molluscan assemblages in subtropical coral reefs

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Molluscs represent an essential component of coral reef ecosystems, although their assemblages remain largely unknown, particularly on subtidal coral reef-associated hard substrata. Understanding their distribution and building predictive models of community composition as a function of environmental variables therefore constitutes a key issue for management of molluscan assemblages. We adopted a hierarchical sampling method; quadrat, transect, reef, and estuary. The study was conducted from June to September of 2011 on 3 transects within 3 fringing coral slopes (about 7m in depth) among 12 estuaries in Okinawa Island, south-western Japan. Molluscs were sampled by visual census and collected by hand within 15 quadrats (0.25 m^2) haphazardly located along a belt transect of 15 × 1m. For environmental variables, water chemistry (e.g., pH, salinity, DO, turbidity), biogeochemical properties (C:N, C and N stable isotopic signatures) of fine particles, physical environmental variables (e.g., geomorphology at multiple spatial scales, current strength) and biotic conditions (e.g., community composition of sessile foundation species) were estimated. The aim of this study was to assess the relative contributions of these factors to the molluscan assemblages and the hierarchy of their influence, and develop a predictive model through multiple statistical approaches.

11A Ecology & macroecology
Wednesday 11 July, 1040, Hall D

Nested biogeographic structure of Indo-Pacific coral species

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To address the challenges of global environmental change, we must understand ecological organisation at large spatial scales, and identify the processes that generate and maintain such patterns. We tested among six alternative models of biogeographical structure for Indo-Pacific coral species: nestedness, checkerboard, evenly-spaced, Gleasonian, Clementsian and random. Our analysis identified nestedness as the primary structure: a predictable order of species loss, such that depauperate sites form subsets of more speciose sites. Detailed analysis revealed that species are lost in clusters, suggesting the presence of biogeographical barriers that impact large numbers of species in a similar fashion. These barriers also provide an objective basis for dividing the Indo-Pacific into distinct biogeographical subregions. We exploited the nine subregions identified to explore the causes of nestedness by digitally mapping subregions and barriers, and fitting alternative models for the biological and environmental determinants of those barriers. Specifically, for each barrier, we determined which species traits best explained which species would cross the barrier. We also determined which environmental variables best explained the particular locations of these biogeographical transition zones, providing a more direct test of the causes of species-richness gradients than methods of correlating species richness with environmental variables. These results reveal how dispersal barriers and ecological specialisation, in particular, play important roles in shaping biogeographical structure within the Indo-Pacific.

11A Ecology & macroecology
Wednesday 11 July, 1415, Hall D

The ecology of crustacea on coral reefs

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Coral reefs host a multitude of microhabitats, each with distinct biotic and abiotic characteristics. The Epilithic Algal Matrix (EAM) is a particularly ubiquitous microhabitat, covering most hard substrates. It is often more abundant than live coral in terms of percent coverage. The EAM is composed of four major constituents: algae, detritus, sediments and invertebrates. The trophic importance of algae and detritus is relatively well understood, however, little is known of the invertebrate component. Using a modified vacuum sampler, the abundance and diversity of the EAM invertebrate fauna were quantified. Nocturnally migrating invertebrates were captured using emergence traps positioned over areas of EAM substrate. This study revealed that crustaceans are a particularly important component of the EAM invertebrate fauna. Harpacticoid copepods were remarkably abundant, reaching mean densities of 239,732 individuals per square metre. Furthermore, the EAM faunal assemblage was found to be profoundly different to the emergent community, in both diversity and abundance, indicating a change in the availability of crustaceans to diurnal and nocturnal predators. Gut content analysis of the local fish populations revealed that crustaceans were also a major contributor to the diet of benthic predators, of which harpacticoid copepods were a prominent component. The results presented here suggest that crustaceans in the EAM are fundamentally important as valuable links in trophic pathways, as facilitators for the rapid linear growth of small fishes, and as important drivers of coral reef energetics.

11A Ecology & macroecology
Wednesday 11 July, 1145, Hall D

Connectivity, species size and the functioning of reef fish assemblages

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Most studies focusing on the functioning of reef fish assemblages look into diversity, diet and spatial patterns, but very few have investigated the importance of species size. Three major results are linked in the present study to show that species size is central to the understanding of the functioning of these assemblages. 1) the

proportion of large reef fish species increases as physical connectivity decreases on a world-wide scale (based on the analysis of more than 160 checklists); 2) the slope of the relationship between diversity and biomass of reef fish also increases when physical connectivity decreases (based on visual censuses of more than 80 sites worldwide); 3) several life history traits are correlated to a combination of connectivity and species size: pelagic larval duration, geographical range, egg batch, length of the reproductive period, adult home range; in contrast diet and several behavioral traits are not correlated. These life-history traits may explain a higher dispersal and colonization success of large species versus smaller species in areas of low connectivity, compared with a higher colonization success of the smaller species on large islands or continental shelves.

11A Ecology & macroecology
Tuesday 10 July, 1715, Hall D

Population dynamics of four unique *Acropora cervicornis* populations

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There are limited studies investigating population ecology of the threatened coral *Acropora cervicornis* across several regions. In order for managers to appropriately develop recovery plans, a broader understanding of population dynamics across the species range is needed. Over a period of four years we have surveyed multiple *A. cervicornis* populations within southeast Florida and have recently expanded our efforts to the Florida Keys, Dry Tortugas, Florida and Veracruz, Mexico. The aims of this study were to quantify, describe and compare the *A. cervicornis* populations across multiple regions. Within each region multiple plots and transects were installed to evaluate population structure and sources of mortality. Population structure is varied, with southeast Florida and Veracruz having locally dense patches while the Florida Keys and Dry Tortugas populations tend to be scattered individual colonies. In terms of colony size, the southeast Florida region had significantly larger colonies than all other regions. However, there were no significant differences in branch length, diameter or canopy height. Coral predation by *Hermodice carunculata* (bearded fireworm) and *Stegastes planifrons* (three spot damselfish) was recorded in all regions. Predation from *Coralliophilia abbreviata* (snail) was only documented in the Keys and Veracruz populations. In contrast to past observations of white band disease being a major source of mortality, we documented a disease-like condition known as rapid tissue loss as affecting all populations at varying levels of severity and the condition appears to be seasonal. This effort provides valuable information at several spatial scales, which will facilitate management of this threatened species.

11A Ecology & macroecology
P107

The macroecology of reef fish body-size distributions

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The frequency distribution of body size for a species assemblage is an emergent macroecological pattern that reflects processes operating at local to global scales. Given that body size is a key determinant of species' life history and ecological role, size-frequency distributions for entire species assemblages, and how these distributions vary with spatial scale, and among habitats and regions, may yield important insights into the ecological processes that structure biota. Here we undertake the first assessment of size-frequency distributions for marine vertebrates. Consistent with results reported for mammals, size-frequency distribution of reef fish is modal and right-skewed for some regions as a whole, but. However, in contrast to results reported for mammals and birds, it does not becomes flatter at smaller scales, when species-level data are binned into logarithmic size categories. Furthermore, the overall size-frequency distribution of the world's marine fish is lognormal rather than right-skewed. Moreover, different patterns emerge if these global data are subdivided by habitat type: the size-frequency distribution is significantly right-skewed for reef-associated fish, but left-skewed for pelagic species. These findings can be reconciled based on fractal niche theory, which predicts an increase in the prevalence of small-bodied species with spatial habitat complexity. An analysis incorporating distinct biogeographic regions identifies reef area, coral-species richness and reef isolation as significant correlates. Our comparative approach of variability in scale-dependent patterns among regional assemblages has brought several insights into the long-term controversy between the contribution of niche-based competition and stochastic dispersal as structuring factors of reef fish assemblages.

11A Ecology & macroecology
Tuesday 10 July, 1545, Hall D

Quantify relationships among coral mechanical vulnerability, habitat complexity and niche space

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At the scale of most coral reef-associated organisms, habitat structure is largely a function of the local coral assemblage. Assemblages are composed of different-shaped and -sized colonies that, over time, break or die and become part of the non-living reef matrix. The habitat complexity provided by coral assemblages is constrained by the hydrodynamic environment, which acts to limit the degree to which coral colonies can exist and grow to large sizes and subsequently reduces the number of potential niches available to other reef organisms. In this study, we quantify relationships between mechanical vulnerability and habitat complexity using two mechanistic measures, colony shape factor and fractal dimension. These capture a colony's vulnerability to wave forces, and the number of different-sized organisms that can potentially fit within it, respectively. We measure these properties for thousands of coral colonies representing a wide range of species and growth forms, and at a series of hydrodynamic exposure locations, from sheltered back-reef lagoons through outer ribbon reef crests. As expected, we find that fractal dimension decreases as a function of hydrodynamic exposure. However, relationships differ markedly among species, highlighting growth strategies that are especially effective at maintaining high fractal dimensions and large sizes in exposed habitats. As a consequence, habitat complexity decreases more gradually than habitat mechanical vulnerability as hydrodynamic exposure increases. These findings suggest that climate change-associated increases in storm intensities and/or the weakening of calcified materials will likely influence the diversity of reef-associated organisms to a lesser degree than coral taxonomic and morphological diversity.

11A Ecology & macroecology
Wednesday 11 July, 1215, Hall D

Associations of genetically distinct *Symbiodinium* with global ocean climate data

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In this study, we model the realized niches of *Symbiodinium* algal clades using a published global database of >500 spatial *Symbiodinium* observations and ocean climate variables. Environmental variables included radiation variables [photosynthetic active radiation (PAR)], ocean color turbidity product (Kd490), and a number derived from sea surface temperature (SST), such as temperature variability (standard deviation), magnitude (maximum, minimum, mean), distribution (kurtosis, skewness), and thermal stress metrics (thermal stress anomaly, weekly sea surface temperature anomaly). Principal component (PC) analysis was used to extract SST dimensions from the time series spatial data and the prominent PCs were used in the analysis. MaxEnt and BIOMOD were used to model the probability of occurrence of each clade spatially as a function of the ocean climate variables. Preliminary results identify the fundamental niches of all clades, the differences in distribution patterns among clades, and the relative contribution of the predictor variables to these patterns. In general, variables that represent SST magnitude, and thermal stress metrics, albeit at varying degrees, predicted the highest variability in the distribution of all clades. PAR and turbidity were more strongly associated with Clades D and B, while Clade D distribution was mostly explained by high PAR and temperature magnitudes. These distributions are discussed in the context of the application of conservation genetics and the spatial planning management of coral reefs.

11A Ecology & macroecology
Wednesday 11 July, 1230, Hall D

Nutritional basis of corallivory in the Red Sea

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Corallivory is a surprisingly common feeding strategy on coral reefs, yet our understanding of what drives prey selectivity among corallivores is limited. Previous attempts to

elucidate the relationship have had limited success but used only one of the three main macronutrients (lipid, protein, and carbohydrate) in any one model. We use nutritional geometry to compare the macronutrient composition of gut samples from parrotfishes and butterflyfishes to that of coral tissue and build a three-dimensional model that takes into account both individual and interactive effects of macronutrients on the fishes' dietary choices. In 2011, four species of butterflyfish (*Chaetodon austriacus*, *C. fasciatus*, *C. larvatus*, and *C. trifascialis*) and three species of parrotfish (*Cetoscarus bicolor*, *Chlorurus sordidus*, and *Scarus frenatus*) were collected along the central Saudi Arabian Red Sea coast, as well as ten species of scleractinian coral and two species of soft coral. All samples were analyzed for total lipid, protein, and carbohydrate content. This is the first study to examine the influence of all three macronutrients on dietary selectivity in corallivores. Combining all three macronutrients in our model allows us to predict the role of macronutrients in determining dietary selectivity among Red Sea corallivores.

11A Ecology & macroecology
Wednesday 11 July, 1445, Hall D

Pearl oysters (*Pinctada*) of Midway Atoll, Northwestern Hawaiian Archipelago

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Pearl oysters (*Pinctada* spp.) may be an important component of coral reef ecosystems due to their community interactions, water filtering capacity, and potential for bioremediating nutrient and heavy metal pollution. Two species, *P. margaritifera* and the smaller *P. radiata*, have been reported previously from the Hawaiian Archipelago. Adult *P. margaritifera* are extremely rare at Midway Atoll, with only 13 located in 6 years of extensive bivalve surveys and other field work. Genetic analyses, using the nuclear ITS1 and mitochondrial COI markers, have identified most 2010 and 2011 *Pinctada* recruits on Midway Atoll as a third species, *P. maculata*, previously undocumented from the Hawaiian Archipelago. A population matrix model for the genus *Pinctada* has been developed and parameterized using field measurements of recruitment, survival, and growth of *P. maculata* on Midway Atoll, as well as survival and growth of adult *P. margaritifera* on Midway Atoll, and published data on distributions, abundances and size-distributions of *Pinctada* species from other locations. This model is used to project population sizes and dynamics of both *P. margaritifera* and *P. maculata* for several Hawaiian localities, and to explore the impacts of possible management options.

11A Ecology & macroecology
Wednesday 11 July, 1035, Hall D

Predicted fish diversity erosion from coral habitat loss

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Reservoirs of biodiversity, coral ecosystems are currently in decline due to local human activities and global change. The latest assessments are alarming with 20% of the world's reefs already destroyed, 24% in grave danger and an additional 26% likely to be by the year 2050. These projections have even more resonance given that coral reefs directly provide food resources, mainly via fish catches, to a large part of the world's poorest people. Beyond delivering protein resources, fish are also essential to sustain many ecosystems processes in coral reefs. Thus the rate and intensity of fish biodiversity erosion on coral reefs due to habitat loss are of major concern for both conservation and ecosystem functioning. Here we used a recent statistical framework based on the endemics-area relationship, instead of the species-area relationship, to estimate fish extinction rates following coral reef habitat loss. Across four Pacific regions (New-Caledonia, Tonga, Fiji and French Polynesia) we built endemics-area relationships using underwater transects for different fish trophic groups: piscivorous, carnivorous, planktivorous, herbivorous and corallivorous. In accordance with the trophic theory of biogeography, which posits that the level of specialization shapes species distribution patterns, we expect two-times higher extinction rates for piscivorous and planktivorous species than for the other trophic groups following coral habitat loss whatever the region. The next challenge is to determine the ecosystem consequences of such unbalanced extinction rates among fish trophic groups.

11A Ecology & macroecology
Wednesday 11 July, 0930, Hall D

Population viability analysis of *Seriatopora hystrix* in Okinawa.

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The mass bleaching that occurred in 1998 devastated almost all populations of Acroporidae and Pocilloporidae in Okinawa Island, Japan. Although there has been some recruitment of Acroporids, recruitment of the short dispersal coral *Seriatopora hystrix* has not been observed since the mass bleaching. As a result, at Okinawa Island, *S. hystrix* is facing local extinction. In contrast, populations of *S. hystrix* have persisted in the Kerama Islands, located 30 km away from Okinawa Island. In order to examine the viability of the populations, we constructed an individual based model for local population dynamics and estimated life-history parameters, such as mortality, growth, and recruitment rates, from field observations of a fixed quadrat at Urunosachi, Kerama islands in 2009 and 2010. Numerical simulation indicated that populations of *S. hystrix* are unlikely to recover via natural recruitment in Okinawa because of the lack of recruitment, and that colony transplantation, if done as a single event, also would not promote population recovery. The Urunosachi population gradually declined during the study period, and the simulation indicated that it came close to extinction after 10 years. Sensitivity analysis showed that improvement in the growth rate of the partially-dead colonies enhanced population persistence. Another scenario that would maintain the Urunosachi population is mass larval recruitment, from other populations, which is larger than the observed recruitment level. This result indicates that further research is required to locate other *S. hystrix* populations near the Urunosachi population, and to evaluate the strength of connectivity among populations.

11A Ecology & macroecology
Wednesday 11 July, 1130, Hall D

Growth pattern and annual increment of tabular type corals

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Growth pattern and annual increment of two tabular type corals were studied by digital camera method. One species was *Acropora hyacinthus* at Sekisei Lagoon, western Okinawa, and another species was *Acropora solitaryensis* at Amakusa, western Kyushu, Japan. We took scaled photos of marked specimens with an underwater digital camera, and repeated this after one year. After calculating the difference of maximum length of the specimens, annual increments of each specimen were plotted. Regression equations in several cases were parallel to the line of y=x. The regression equations of other organisms generally intercept the unity line (y=x), because there are maximum sizes in most organisms. So, this 'parallel' means that there is no size limitation for these coral species and their growth is indeterminate. Also, the value of the vertical intercept (the intersection of the regression equation and the y-axis) shows the average annual growth increment. The average annual growth of *A. solitaryensis* from 2000 to 2001 was calculated as 7.5 cm in diameter. Annual growth was similar among *A. solitaryensis*, but more variable in *A. hyacinthus*.

11A Ecology & macroecology
Wednesday 11 July, 1200, Hall D

Post-settlement events influence on coral population structure: A multi-scale analysis along a latitudinal gradient

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Although recruitment processes are known to influence spatial patterns of adult coral assemblages, the relative influence of recruitment processes vs. post-settlement events in population maintenance remains poorly known. Yet, understanding how populations are maintained is a pre-requisite for efficient management. The present study analyses the influence of post-settlement events on adult population structure in several habitats and locations of three regions following a latitudinal gradient: Australian Great Barrier Reef, New Caledonia, and French Polynesia. To address this goal, juvenile mortality and growth of the three coral taxa *Acropora*, *Pocillopora* and *Porites* were assessed, as well as adult population structure, following a hierarchical sampling design. *Acropora*, *Pocillopora* and *Porites* are dominant genera throughout the Pacific, and present different

life-history traits. Some patterns were conserved among regions and locations, such as a general decrease in juvenile mortality with colony size. *Porites* tended to present a lower mean mortality, but also a lower mean growth than *Pocillopora* and *Acropora* in all regions. In contrast, juvenile mortality and growth showed high variability among habitats and depths, spatial patterns of this variability were not consistent among regions, and were not connected to adult population structure. Juvenile mortality over 6 months also displayed a very high temporal variability in French Polynesia over the 2 year duration of the study, ranging from 28% from March to September 2010, to as high as 74% from September 2009 to March 2010, whereas it was more consistent over time in the other two regions.

11A Ecology & macroecology
Wednesday 11 July, 1000, Hall D

Diversity components, climate change and predators role after 15 years of no-fishing

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The Cabo Pulmo MPA is designated as a Natural Humanity Heritage site by UNESCO. It is located in the south of the Gulf of California in a transitional zone between tropical and subtropical regions, which makes it particularly sensitive to seasonal, interannual and decadal oceanic processes. Commercial fishing stopped at this locality more than 15 years ago; for this reason, ocean-climate, not fishing, has been the main forcing factor of documented variability in fish community attributes. The aim of this work is to analyze the long term fluctuations in fish assemblages, assessing the impacts of both an increase in the abundance of commercial fishes (mainly predators) and the ocean-atmosphere conditions, on overall observed ecological signals. According to initial results, the density of commercial fishes was statistically higher than 2003 (Kruskall-Wallis; $H_{10,\ 340}$=73.7; p<0.05). Several multivariate models showed significant relationships between functional groups and abiotic variables, among which protection was selected repeatedly (P_s=0.464; p<0.001). Results for diversity components (α,β,γ) are discussed in order to provide an understanding of the progressive role of predatory fish in a no-take scenario. The evidence suggests that during the period 1995-2010, predation events and oceanic conditions have driven similar patterns in several community descriptors (S, H´, J´, λ). However, it has been possible to detect that protection has promoted greater predation intensity, leading to the regulation of competition relationships among fishes of lower trophic levels, thus allowing the proliferation of dominant species.

11A Ecology & macroecology
Tuesday 10 July, 1750, Hall D

The cascading effects of predators on coral reefs

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Predation can be a strong, structuring force in marine ecosystems. The effects of predators are typically thought to be direct, reducing the density and/or biomass of populations in lower trophic levels. Such changes in density of one trophic level can cascade through to subsequently lower trophic levels in a so-called trophic cascade. Interestingly, little evidence exists from coral reef ecosystems consistent with linear trophic cascades, perhaps due to the high levels of complexity typical of tropical marine ecosystems. Yet a host of consistent changes in ecosystem structure and functioning appear to be coupled with the removal of predators. I will discuss our investigations into the generalized changes associated with predator removal from coral reef ecosystems. These changes range from structural (e.g., shifts in species composition, size structure of prey, prey life history) to dynamical (e.g., reductions in fisheries productivity and loss of ecosystem resilience). I will present results from a series of observational and experimental studies tailored to address these predictions, with work principally conducted in the tropical central Pacific.

11A Ecology & macroecology
Wednesday 11 July, 0945, Hall D

Diversity and stability of herbivorous fishes on coral reefs

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Biodiversity may provide insurance against ecosystem collapse by stabilizing assemblages that perform particular ecological functions (the 'portfolio effect'). However, the extent to which this occurs in nature, and the importance of different mechanisms that generate portfolio effects, remain controversial. On coral reefs, herbivory helps maintain coral dominated

states, so volatility in levels of herbivory has important implications for reef ecosystems. Here we use an extensive time series of abundances on 35 reefs of the Great Barrier Reef of Australia to quantify the strength of the portfolio effect for herbivorous fishes. Then, we disentangle the contributions of two mechanisms that underlie it: compensatory interactions, and differential responses to environmental fluctuations ('response diversity'), by fitting a community-dynamic model that explicitly includes terms for both mechanisms. We find that portfolio effects operate strongly in herbivorous fishes, as shown by nearly independent fluctuations in abundances over time. Moreover, we find strong evidence for high response diversity, with nearly independent responses to environmental fluctuations. In contrast, we found little evidence that the portfolio effect in this system was enhanced by compensatory ecological interactions. Our results show that portfolio effects are driven principally by response diversity for herbivorous fishes on coral reefs. We conclude that portfolio effects can be very strong in nature, and that, for coral reefs in particular, response diversity on coral reefs may help maintain herbivory above the threshold levels that trigger regime shifts.

11A Ecology & macroecology
Tuesday 10 July, 1645, Hall D

Gastropod predation on staghorn coral *Acropora tumida* in Hong Kong

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Predation on corals by corallivorous gastropods is a source of significant impacts on many coral reefs, causing mass mortality of coral species or changes in the structure of the reef community. In 2000, prolonged low winter sea surface temperatures (SST, 14℃) were recorded in Hong Kong. This was followed by a serious predation problem by corallivorous gastropods. In the subsequent three years, with milder mean winter SST (>17℃), the predation effect on corals was minimal. It is thus hypothesized that low winter SST may have weakened the corals, especially *Acropora* spp., thus attracting extensive gastropod predation on these corals. To verify this hypothesis, two sites (A Ye Wan and A Ma Wan) in Tung Ping Chau Marine Park were chosen for the study, and 15 *Acropora tumida* colonies from each site were tagged for monthly monitoring. The winter of 2009-2010 was quite warm (mean SST: 17.69℃), and the subsequent predation pressure was quite weak. Most of the tagged colonies did not show significant increase in area of feeding scars. However the winter of 2010-2011 was much colder (mean SST: 15.55℃), and the subsequent predation pressure in the spring and summer was higher. Almost all of the tagged colonies showed an increase in the area of feeding scars, although without a significant increase in the density of the corallivorous gastropods. These results appear to support, at least partially, the hypothesis that colder winters may have weakened *A. tumida*, making them easier targets for corallivorous gastropod attack.

11A Ecology & macroecology
Tuesday 10 July, 1735, Hall D

Living on borrowed time: transgressing unrecognized tipping points

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Regime-shifts, threshold behavior, and alternate stable states are common features of many social, ecological and climate systems. Most recent ecological theory and modeling of coral reefs have focused on equilibrium conditions and end-points. Consequently, the additional nonequilibrium dynamics before and after crossing thresholds are often overlooked. Here we use a model and a review of empirical evidence to show that transient behavior during regime shifts can unfold slowly and imperceptibly. Indeed, many vulnerable ecosystems, and the people who depend on them, may already be living on borrowed time because of our inability to recognize slow ecological responses to tipping-points already passed. However, delayed responses by ecosystems to transgressing a threshold could also afford an opportunity to return to safer levels of system drivers, before the new state eventually equilibrates. In this context, the most important slow regime shift is a social one: convincing enough people to confront business-as-usual before time runs out.

11A Ecology & macroecology
Tuesday 10 July, 1515, Hall D

The ecology of coral larvae: Recent findings

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While historically believed to be 'helpless' and 'passive particles', recent studies have revealed that coral larvae show unexpected behavior, decision-making abilities, and complex interactions with the environment.

Based on recent field and laboratory studies from Curacao, this presentation provides examples of unexpected relationships between the environment, benthic community composition, microbes, and coral larval performance. Main findings illustrate that (1) coral larvae use sound for navigation while in the plankton, (2) aposymbiotic larvae actively search for zooxanthellae before settling, (3) larval settlement behavior depends on the presence of conspecific corals, and (4) that environmental gradients at small spatial scales (e.g., the presence of oxygen gradients around turf algae) cause spatial patterning in settlement locations of larvae. Understanding the dynamics that operate during the earliest stages of new coral community development might provide useful insights that could help to define the conditions required to ensure the survival of recently settled corals, i.e., the reef communities of the future.

11A Ecology & macroecology
Wednesday 11 July, 1115, Hall D

A primary production budget for a Caribbean reef lagoon

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High productivity driven by photosynthetic primary producers, primarily corals, is a key ecosystem service provided by coral reefs. Today, many reefs, particularly in the Caribbean, are no longer dominated by scleractinian corals. Instead, other autotrophic organisms have entered the stage, but their contribution to and influence on overall reef productivity are not resolved. This study therefore investigates net and gross photosynthesis by all dominant groups of primary producers in a typical reef of the Mexican Caribbean, including carbonate sand associated microphytobenthos (40% benthic coverage), sea grasses (29% benthic coverage), macroalgae (25% benthic coverage), and scleractinian corals (1% benthic coverage). A series of incubation experiments were carried out to assess photosynthetic and respiratory oxygen fluxes. For each primary producer, a specific 2D to 3D approximation factor was determined by relating projected area to actual surface area, and their relative contribution to overall lagoon productivity was quantified. Net reef lagoon primary production was mainly driven by macroalgae and microphytobenthos (97% of total net productivity) with only small contributions by seagrasses and corals (3% of total net productivity), while seagrasses exhibited the highest respiration rates. Overall, a primary production budget was calculated for the investigated reef lagoon and compared to other marine tropical ecosystems, particularly coral-dominated reefs. These data provide a fundamental basis to assess the impacts of phase shifts on reefs moving from coral to dominance by other organisms, with respect to ecosystem productivity.

11A Ecology & macroecology
Wednesday 11 July, 1500, Hall D

Coral reef resilience across US-affiliated islands in the Pacific Ocean

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Evidence suggests that coral reefs free from local direct human impacts (e.g. fishing, pollution) are more resilient to punctuated global insults (e.g. temperature anomalies) than those that are not; however this notion remains largely untested. Because of the myriad complexities and inherent natural variation of coral reef communities, large-scale and well-replicated datasets are essential to provide powerful analytical insights. Pacific coral reefs are particularly well-suited for these macro-ecological comparative analyses because they are distributed across many island chains, spanning gradients in oceanographic regimes and levels of human disturbance. The Coral Reef Ecosystem Division of NOAA has been collecting data on coral reef health across the Pacific for the past 10 years; in particular benthic towed-diver surveys provide high spatial, as well as temporal, coverage, often surveying entire island circumferences. This data set offers an unprecedented opportunity to learn how variations in global climatic and human disturbance forcings, and their interactions, affect coral reef resilience. Using individual islands as replicates we quantified the change in hard coral cover at 39 US-affiliated islands spanning four archipelagos (Hawaiian Archipelago, American Samoa, Mariana Islands, and the Pacific Remote Island Areas) over the past decade. Inter-island patterns of benthic change reveal three striking features: (i) sensitivity to a suite of physical forcings including temperature, ocean productivity, wave energy, and predator outbreaks, (ii)

spatial autocorrelation in benthic shifts, and (iii) context-specific capacity to recover from large-scale coral mortality events.

11A Ecology & macroecology
Wednesday 11 July, 1545, Hall D

11B Phase shifts & alternative states on coral reefs

A multi-model approach to understanding benthic community dynamics

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Managing for resilience necessitates an understanding of coral reef benthic dynamics and the processes that drive them. Due to the inherent complexity of the coral reef benthos, modeling is an increasingly prominent tool for investigating relevant demographic and ecological dynamics. To date, reef benthic models vary not only in their formulations of interactions (e.g. competition), but also in their treatment of space, with structures spanning from non-spatial energy-based models to more spatially explicit grid-based models. Because most model formulations weigh particular dynamics differently, we sought to compare dynamical behavior and time-series predictions for three published benthic models that differ mainly in their treatment of space. We parameterized the models to mimic dynamics of a typical, shallow Caribbean reef habitat by estimating the necessary biological rates (i.e. rates of growth, mortality, and recruitment). To test the relative performance of each model, we compared outputs with observed time-series data from a three-year dataset of biannually surveyed permanent photoquadrats from the island of Curaçao. We find predictions of benthic composition and size-frequency distributions for major functional groups (e.g. coral, turf algae, macroalgae), are greatly improved by including explicit spatial dynamics in the model. This multi-model approach allows us to compare the relative importance of particular vital rates and dynamical structures, thus providing a guide for field experimentations. We conclude with a discussion of how modeling permits us to link demographic and ecological rates to the emergent structure of the benthos, and why it is an important tool for management of coral reef ecosystem resilience.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1730, Hall D

Factors driving the loss of *Montastraea*-dominated communities on western Atlantic reefs

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Over the last 15 years the massive framework coral, *Montastraea annularis* (complex) has experienced a rapid decline in abundance, size and condition, and on many reefs in the western Atlantic these species are no longer the dominant corals. Surveys conducted in Puerto Rico, the Cayman Islands, Bonaire, and the Bahamas show a similar die-off and replacement by other corals, aggressive invertebrates and macroalgae, although the timing of these events is variable. Widespread colony mortality has been triggered by mass bleaching events, with coral diseases emerging after corals began to recover from bleaching. Outbreaks of yellow band disease and white plague remain the primary threat affecting these species, although other diseases, fish predation, competition with algae, and overgrowth and bioerosion by sponges are contributing to further losses. While other corals have been impacted by coral bleaching and disease, *M. annularis* colonies have sustained the highest levels of partial and whole-colony mortality. *Agaricia agaricites*, *Porites astreoides* and other brooding species, as well as broadcast spawners, exhibit successful recruitment and colonization of reef substrates and exposed skeletal surfaces of *M. annularis*. In contrast, few recruits of *M. annularis* have been documented, and formerly large colonies that have survived now consist of small tissue isolates that continue to shrink in size. While much attention has focused on the decline of Caribbean acroporids, the loss of *M. annularis* (complex) is of much greater concern as these are much longer lived, slower growing and less able to recolonize a reef through sexual recruitment or fragmentation.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1000, Hall D

Macroalgal shifts on Lakshadweep atolls: herbivore size and environmental factors

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Coral-macroalgal phase shifts have received a great deal of attention. Studies, however, often suggest that we do not yet understand the process thoroughly. We studied herbivory and phase shift relationships on the Lakshadweep islands, where fish populations are untouched by fishermen. The study explores how these relationships differ among different parts of the reef and how different sized herbivore groups may play different roles in the coral-macroalgal balance; as larger herbivorous fish are thought

to play a major role in keeping reefs in a coral-dominant state. We experimentally manipulated herbivore density on Agatti atoll using exclusion cages of two mesh sizes. One excluded all fish and urchins; the other excluded only large fish. Both cages (40x40x25 cm), with controls, were installed on 24 sites. Sites were grouped into pairs: A) closer to the reef crest, B) closer to the lagoon. The sites were situated along the reef starting from the lagoon's main channel moving further onwards along a gradient of water current. After 5 months, macroalgae in small-mesh cages stabilised at 16.9 mm height with 100% coverage, however the big-mesh cages underwent no significant change (height 2 mm, 52% coverage). There was also a significant difference in algal growth between sites A and B, and along the gradient, suggesting that the decline of herbivores may have different impacts under different environmental conditions. Our results indicate that the importance of small herbivores may have been significantly underestimated, and suggests that the mechanisms of coral-macroalgal phase shifts may be more complicated and site-specific than earlier thought.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1645, Hall D

Reef community variability among alternative states in the inner Seychelles

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The persistence of alternative coral reef states is highly variable and intrinsically linked with the recovery process. Various fundamental ecological factors that influence the entire reef community assemblage are therefore involved in the persistence of alternative states. In order to understand their relative influence, variability in community assemblages and characteristics of reefs in transition or within differing alternative states needs to be examined. We conducted a series of ecological surveys in September 2010 across the inner Seychelles coral reefs, measuring variation in underlying substrate, benthic biota and fish assemblages. Ordination of benthic biota indicates that a gradient from coral dominated reefs to reefs in alternative states such as macroalgae or turf domination exists. Similar reef groupings were found when investigating the fish assemblages, reflecting the potential for characteristic reef fish assemblages to occur among benthic reef states. However, a gradient of underlying substrates, from rubble to consolidated reef substrates, did not match the benthic cover gradient, with reefs in different benthic states found across the range of underlying substrates. A combination of ordinations and regression analyses were used to determine the particular assemblages of benthos and associated fish communities that define specific alternative reef states. The findings provide important insights into the differing ecological compositions of alternative states on coral reefs and the ecological characteristics of recovering versus deteriorating coral reefs.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1145, Hall D

Regime shifts on Hawaiian coral reefs: from coral to sediment

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Fringing coral reefs in Hawaii are periodically disturbed by events of short-term (days) to long-term (decades) duration that are both natural and human-induced. Although not all such events result in lasting impact to adjacent coral reefs, when they do, the result can be severe, relatively sudden, and irreversible. Deposition of terrigenous sediment, and its frequent resuspension, for example, are key causes of disturbance in Hawaii and other high islands. During seasonal storms, heavy run-off of water and sediment occurs from watersheds impaired by feral grazers, agriculture, deforestation, ranching, and urbanization. Large areas of dead coral on fore reefs of the Hawaiian islands of Molokai, Lanai, and Maui appear to be related to recent sedimentation events. Observations of recently stressed colonies show that coral death was followed by relatively rapid erosion by organisms and generation of carbonate sand (dominantly coral and crustose coralline algal grains). The reef-derived sand, in turn, hosts Halimeda, a renewable source of sediment that further buries potential recruitment sites and abrades remaining coral and new recruits. Living coral in these areas is restricted to the tops of reef remnants 15 cm or more above the surface of the sand plain, of which Halimeda-derived grains are a significant component. The end result is a regime shift from stable coral-algal community to stable sand plain, with little likelihood of reversal. Our observations indicate that many square kilometers of coral habitat have been lost from Hawaiian reefs through the processes of coral reef conversion to sand plain.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 0945, Hall D

Phase shifts and sediment pulses on coral reefs

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It is widely accepted that sediments pose considerable threats to coral reefs. However, little is known about the role of sediments at ecologically relevant scales. I will describe a potentially deleterious negative feedback loop in which sediment bound in algal turfs on reefs suppresses herbivory by reef fishes, reducing top-down pressure on the turfs, allowing increased algal growth and increased sediment retention. A combination of caging and sediment removal studies was conducted to quantify the strength of the proposed feedback loop. Sediment mediated suppression of reef fish herbivory was found to lead to a phase shift to a stable state dominated by long algal turfs. High wave energy appeared to prevent the development of macroalgae, but it did not prevent a phase shift to a sediment-laden turf (gritty turf). Furthermore, while reefs might have the capacity to recover from this phase shift, recovery appears to be dependent on unusually high fish abundances. By ingesting both algal turfs and sediments, many herbivorous/detritivorous reef fishes may act as vectors for biological sediment transport, as such they appear to play an important function in terms of resilience against these phase shifts to 'gritty turfs', by maintaining low sediment, well grazed turfs. With increasing rates of sedimentation and exploitation of herbivorous reef fishes, 'gritty turfs' may become an increasingly prevalent and particularly resilient degraded alternate state on coral reefs.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1200, Hall D

Navigating towards better reef futures

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Managers and policy makers are increasingly recognizing the importance of preventing or reversing phase shifts from coral dominated reefs to persistent reef states dominated by other taxa. Although developments in how to detect and avoid such shifts have been made, reversing phase shifts on the many degraded reefs of the tropics is a far more challenging endeavour. Here we suggest appropriate policy actions can help society navigate reefs toward coral dominated states in the face of ongoing anthropogenic and climatic pressures. Reversing phase shifts will require policy actions across whole reef systems to bolster the resilience of the coral dominated state while simultaneously weakening the resilience of the alternative state. A key component of this will be preparing the system for change, through reducing chronic stressors and strengthening key processes that both weaken the undesirable state and re-establish feedbacks in the desirable state. Such preparation will enable pulse disturbance events, shocks, and extreme variability to be harnessed for shifts back to the coral dominated state, where positive feedbacks can strengthen the coral dominated stable state. Innovative science, policy and governance is required to navigate reefs towards a coral dominated future, reinstating functional redundancy and understanding the metrics, processes and functions that drive system change. Radical changes in coral reef governance to ensure continued provision of critical functions has already occurred across numerous nations, paving the way for improved stewardship of coral reefs into the future.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1115, Hall D

***Acropora cervicornis* in Belize: is staghorn coral coming back?**

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Decline in the abundance of Caribbean/Atlantic *Acropora cervicornis* since the 1980s is well documented. Questions of whether the species will continue to diminish or potentially recover remain open. Locations of persistence and recovery of this keystone species have been reported from the Dominican Republic and Honduras. During summer 2011, the abundance and density of living *A. cervicornis* were documented on a system of patch reefs off Ambergris Cay, Belize, which appear to also show local recovery after recent collapse of the species. The aerial extent of 16 distinct *A. cervicornis*-dominated patch reefs was measured, and range in size from 10-556 m^2. The total area of *A. cervicornis* reef was 2364 m^2 within the Mitchell Rocks area, Belize. Video line-transect, and photographic meter square quadrat survey data were collected on 5 of the patch reefs. Sixty-three quadrat photos were digitized, scaled, and all live *A. cervicornis* tissue was manually outlined in map view. Percent live tissue and number of branch tips were calculated for each image. Live *A.*

cervicornis per m^2 varied from 9-64% with an average of 32%, but individual patches varied from an average of 18-50%, indicating that recovery was heterogeneous across the region. The average number of live branch tips was 240, with a range of 86-545 live tips per quadrat, and a weak correlation between live tissue and branch tips. While time-consuming to process, we think these data will prove valuable in high-resolution characterization of changes in regional area coverage of *A. cervicornis* in the future.

11B Phase shifts & alternative states on coral reefs
P108

Benthic shift in an Solomon Islands' lagoon: corals to cyanobacteria

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In June 2011 a large phytoplankton bloom resulted in a catastrophic mortality event that affected a large coastal embayment in the Solomon Islands. This consisted of a $30km^2$ area of reef and soft sandy habitats in Marovo Lagoon, the largest double barrier lagoon in the world. This embayment is home to over 1200 people leading largely subsistence-based lifestyles, who are dependent on the impacted reefs for the majority of their protein needs. A toxic diatom (*Psuedonitszhia*) and toxic dinoflagellate (*Pyrodinium*) reached concentrations of millions of cells per litre. The senescent phytoplankton bloom led to complete de-oxygenation of the water column, killing the majority of marine animal life in the immediate area, within a rapid timeframe (24 hours). Groups affected included holothurians, crabs, and reef and pelagic fish species. Bloom initiation and persistence of de-oxygenation were likely due to limited local wind and current driven water circulation, and persistent stratification preventing re-oxygenation. Dolphins, reptiles and birds were also found dead within the area, indicating algal toxin accumulation in the food chain. Deep reefs and sediments, whilst initially unaffected, have now been blanketed in large cyanobacterial mats, which are likely to negatively impact reef recovery and may indicate an alternative state for the system. The implications for the ecosystem as a whole, as well as the food security issues will be discussed.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1630, Hall D

Decadal-scale losses in reef complexity and implications for ecosystem services

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Losses of ecological services in coastal ecosystems are usually approximated by changes in area. However, for coral reefs, key ecosystem services such as productivity, beta diversity, energy attenuation and carbon sequestration are more attuned to topographic complexity than simply areal extent. Stressors operate to reduce reef complexity at two spatial scales. Contraction of reef vertical extent may arise from sedimentation and algal overgrowth on reef flats, coupled with shallower lower limits from sedimentation and reduced light availability. At reef scale, these stressors are also associated with diminished topographic complexity through shifts in the dominant growth morphology of corals. These are further affected by climate-related disturbances such as increased storm intensities and frequencies. We present a synthesis of available literature together with meta-analyses of quantitative growth-form data to establish metrics of reef complexity. Significant losses in topographic complexity over decadal scales were found to occur globally, with losses of over 50% recorded in parts of Southeast Asia. The potential effects of these losses on energy attenuation and therefore coastal protection are particularly relevant in the face of climate change.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1530, Hall D

Modelling and testing feedbacks to predict shifts in seagrass ecosystems

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Theoretically, the resilience of an ecosystem to phase shifts is supported by feedback loops that promote self-organisation and resistance to small disturbances. However, understanding of ecosystem shifts has largely been gathered after the shift in state has occurred. The challenge for ecologists is to use a combination of predictive modelling and empirical testing to enable forecasting of sudden shifts in state. We developed a Bayesian Network Model to assess the importance of feedback loops in seagrass meadows, and to test the effects of various management scenarios, on the persistence of seagrass at meadows experiencing different combinations and levels of stresses. The model showed that managing seagrass systems to enhance resilience to

disturbance requires an understanding of the interaction between the strength of regulatory feedback loops and seagrass persistence. The output of the model was then used to inform the design of an experiment focussed on measuring the relationship between the feedback loops, changing environmental conditions, and the subsequent effects on seagrass biomass, in Moreton Bay, Australia. We measured processes from three feedback loops, the uptake of nutrients from the water column, the resuspension of sediments, and grazing rates on algae following a large flood in Jan 2011. We provide empirical evidence that regulatory feedback strengths vary in response to disturbance. The model output and empirical results provide information on the ability of seagrass meadows to buffer multiple stresses, and will enable managers to better manage for the specific stresses that lead to sudden shifts in ecosystem state.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1215, Hall D

Invasive corallimorph associated with shipwreck at Palmyra Atoll Wildlife Refuge

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Phase shifts refer to the relatively rapid changes in dominant biota of a coral reef, and typically involve overgrowth of corals by algae. Phase shifts, documented globally from the Mediterranean and Caribbean to the Pacific Ocean, are generally caused by a major disturbance that allows a competing species to gain a foot-hold and maintain an alternative stable state. Palmyra Atoll is jointly managed by the US Fish and Wildlife Service (Service) and The Nature Conservancy as a National Wildlife Refuge and research station for the Palmyra Atoll Research Consortium, monitoring its coral reefs since the creation of the refuge in 2001. Monitoring revealed an invasive corallimorph, *Rhodactis howesii*, smothering the reefs immediately around a shipwreck. Systematic surveys in 2007 and 2011 by the US Geological Survey and the Hawaii Institute of Marine Biology revealed this phase shift to be unambiguously associated with the shipwreck. Surveys indicate the infestation now covers ca. 3 km square of reef and continues to spread. In June 2011 limited trials to eradicate *R. howesii* from the reefs in small (3 m^2) areas show promise. The partners continue to monitor the spread of the corallimorph and explore options for larger-scale eradication and habitat restoration. This will in turn aid in the management of Wildlife Refuges in the Pacific and help to prevent and mitigate phase shifts on coral reefs. Fiscal constraints and complex remote logistics hamper shipwreck removal from these remote areas and confound managers' ability to protect the otherwise healthy reefs.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1515, Hall D

Positive feedbacks produce alternate community states: empirical and simulation-based evidence

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Recent attention has been focused on the idea that dramatic community shifts represent shifts between alternative stable states (ASS), though robust evidence is lacking. We tested ASS theory on two Panamanian reefs by identifying positive feedback processes that could produce ASS. Using *in situ* assays of algal consumption, growth and nutrient limitation we identified two mechanisms (coral facilitation of herbivory and algal facilitation of nutrient availability) that showed positive feedbacks with community composition. In the coral-dominated state herbivory rates were higher, algal growth was lower and nutrient limitation was stronger than in the algal-dominated state. Using these mechanisms we developed a spatially explicit simulation model of competition for space between coral and algae. The presence of positive feedback mechanisms alone drove rapid shifts between community states, and generated hysteresis in the model by producing separate basins of attraction around coral-dominated and algal-dominated community states under a range of intermediate environmental conditions. Each state persisted over long timescales, indicating positive feedbacks can be sufficient to stabilize alternate community states. In addition, with positive feedbacks present, coral and algae in the model segregated to separate regions of the model space producing sharp boundaries. This corresponded with previous theory and observational surveys of benthic community composition that showed reefs were segregated into distinct patches dominated by either coral or algae. As our model results show that positive feedbacks can be sufficient to produce and stabilize alternate community states, identifying such mechanisms may be a valuable initial diagnostic criterion for identifying possible ASS dynamics.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1500, Hall D

Manipulating feedbacks in degraded coral reef states

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In many areas, coral reefs have shifted into degraded states. Once in these degraded states, feedbacks continue to reinforce an ecosystem that no longer provides the goods and services desired by society. Managing feedbacks poses a major challenge for managers and policy-makers seeking remedial actions to curb the coral reef crisis. A better understanding of the way human actions influence the strength and direction of feedbacks, how different feedbacks interact and at what scales they operate, is crucial for the successful management of coral reef ecosystems. This study synthesizes the interactions of critical feedbacks of the degraded states in coral reefs. It further explores to what extent current management captures these feedbacks, and proposes strategies for how to manipulate interacting feedbacks in a fashion that breaks the resilience of degraded coral reef states. This study illustrates how ecological feedbacks can interact with social dynamics generating social-ecological traps that are difficult to escape, and concludes that management of degraded marine states requires a broad social-ecological approach to succeed.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 0930, Hall D

Markov chain analysis of community dynamics in a degraded reef

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A state of low coral cover persists on a lagoonal reef flat (Bolinao, Philippines), which just over a decade ago, supported large *Porites* microatoll communities. To describe fine scale processes that may be keeping the system in a 'degraded' state, we parameterized discrete time-averaged and density-dependent Markov models using data from permanent plots (2010-2011). In the time-averaged model, probabilities of transition from bare space to sponge, turf, and algae were 2 orders of magnitude higher than those to hard and soft corals. Mean time between disturbances, inferred from recurrence time for bare space, is 1.0 year. The model predicted a community dominated by sponge, with *Callyspongia* sp. contributing the largest to observed frequencies. Stationary community structure was positively correlated with colonization rate, disturbance, and ability to replace/overgrow species from other functional groups. Hypothesis tests based on Bayesian credible intervals detected that 35% of transitions were density-dependent. Most of these involved groups with ~10% observed mean cover. Colonization increased with cover of the incoming group; for other types of transitions, different patterns emerged. Persistence of algae was negatively dependent on cover, while that for sponge was nonlinear, peaking at intermediate levels of cover. Density-dependent simulations starting from 100% space predicted a community dominated by articulated calcareous algae. The matrix modeling approach enabled us to probe for potential feedback loops and to clarify the relative importance of successional processes.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1700, Hall D

Global disparity in the resilience of coral reefs

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Resilience ideas largely stem from coral reefs. To date, most models of resilience have evolved from Caribbean reefs, indicating a strong regional bias. Here we show tremendous regional variability in resilience, phase shifts and the functional response of coral reefs. Previous studies have noted geographical differences in the frequency of phase shifts, but here we review functional differences between major biogeographic regions using comparable datasets. We begin by investigating major differences in the characteristics of phase shifts on coral reefs. We then pose and discuss a series of novel and existing hypotheses that may account for these differences. We finish by considering whether theory developed in one region can be applied to another, and discuss the anticipated implications for science and management of coral reefs.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1015, Hall D

From hard to soft: the current state of reefs in the Florida Keys

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The Coral Reef Evaluation and Monitoring Project (CREMP) has monitored selected reefs in the Florida Keys since 1996. CREMP assessments have been conducted annually at fixed sites and data collected provides information on temporal changes in the benthic cover of stony corals, octocorals, sponges, and macroalgae. Long-term trends of the major benthic taxa and the five most spatially abundant stony corals (*Montastraea annularis* complex, *M. cavernosa*, *Colpophyllia natans*, *Siderastrea siderea*, and *Porites astreoides*) were analyzed from 32 sites. The analyses focuses on the last 13 years of data (1999 through 2011) to evaluate coral recovery following the mass bleaching event of 1997/1998 that reduced coral cover by ~40% in the Florida Keys. Since 1999, stony coral and sponge cover have continued to decline while octocoral cover has increased. No trend was observed for macroalgae. The trends of for *M. annularis* complex, *M. cavernosa*, *C. natans*, and *P. astreoides* were all negative since 1999, and are due to multiple stressors. *Siderastrea siderea* did not show a trend in cover. It is often reported that following severe disturbances on Caribbean reefs, shifts from stony coral to macroalgae or sponge dominated communities occur. While CREMP has recorded ephemeral macroalgal blooms, prolonged increases in abundance have been avoided. Likewise, the cover of sponges has not expanded. Instead, CREMP findings suggest that octocorals are replacing stony corals as the dominant taxa. The transition is most apparent on shallow fore reefs where *Acropora palmata* and *Millepora complanata* were previously abundant.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1230, Hall D

State changes in a coral reef: herbivory, connectivity and recruitment

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Given world-wide trends, it is critical to better understand processes that facilitate the rapid return of reefs to a coral dominated state following pulse perturbations. Since many perturbed reefs have undergone a persistent state shift to high cover of macroalgae, knowledge of how herbivory operates is of paramount importance. However, while control of macroalgae is necessary for a return to coral dominance, it is not sufficient - failure of corals to recruit following a disturbance will keep the reef in a degraded state. Coral settlement rates can scale with adult abundance, so widespread decline in coral cover could lead to persistent recruitment failure. Reefs around Moorea, French Polynesia have consistently returned to coral dominance following major disturbances. Following the most recent perturbation, populations of herbivores - particularly parrotfishes - increased rapidly, which prevented macroalgae from increasing on the forereef despite the near complete loss of coral. The numerical response of parrotfishes was facilitated by the presence of nursery habitat in the lagoon where they recruit before moving to offshore reefs. Recruitment of corals to denuded forereef habitat has been robust, indicating substantial larval connectivity with source populations, although it has been highly variable at several spatial scales: among different sides of the triangular island, along a gradient of plots at the same locale and depth, and between adjacent plots that differ in the amount of dead coral structure remaining. These findings underscore the importance of connectivity and the need to protect functionally critical nurseries that enhance resilience of coral reefs.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1130, Hall D

Specialization affects response of a reef fish community to bleaching

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Coral reef fishes are potentially vulnerable to extinction as a direct consequence of habitat degradation. This risk is greatest for species highly specialised on resources provided by corals, in combination with low abundance or small geographic range. Here, we examine resilience and vulnerability to extinction by examining the interrelationships among patterns of specialization, abundance and distribution in two families of fishes (Pomacentridae, Labridae) at the Keppel Islands (southern Queensland). We evaluated the threat of extinction by comparing abundance before and after an extreme bleaching event caused by the 2010-2011 flooding. Most species were either extreme specialists, had low abundance, or a small range, but no species exhibited all three characteristics. Southern Queensland endemics were consistently more abundant than widespread species and were less reliant on living coral. Specialists were generally less

abundant than generalist species. Following the bleaching, live coral cover and macroalgae declined by 70%, and 85% respectively, with a 300% increase in turf algae. Eighteen of 24 fish species exhibited declines in abundance of over 60%. While many species demonstrated a prior preference for turf algae, only 4 species showed an increase in abundance. Of the 5 endemic species, 1 increased, while the other 4 showed declines similar to the widespread species. Overall there was a positive relationship between specialization and population decline. The 3 most specialized species showing preferences for live coral exhibited declines of 87-100%. While some ecological versatility was observed, the magnitude of the response suggests many species will be vulnerable to large-scale bleaching events.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1545, Hall D

Baselines and degradation of central Pacific benthic reef communities

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Numerous studies have documented a declining abundance of reef building corals across the globe, over the past several decades. In some cases these losses have been associated with phase shifts to dominance by fleshy macroalgae. These assessments however, often ignore the remainder of the benthos and therefore prevent scientists from truly understanding the present day structure and function of many reefs around the world. Here, using an unprecedentedly large data set collected within the last 10 years across 60 islands and atolls and 5 archipelagos across the central Pacific, we examine how benthic reef communities differ in the presence and absence of human populations. Using islands as replicates, we examine whether benthic functional group abundance is associated with human habitation within and among archipelagos. We find striking similarities in benthic communities from inhabited islands, independent of archipelago, where the majority of the benthos is composed of fleshy non-reef building organisms (turf algae, fleshy macroalgae and non-calcifying invertebrates). In contrast benthic communities from uninhabited islands are much more variable, but in general are dominated by calcifiers and active reef builders (corals and crustose coralline algae). These results suggest that cumulative human impact on coral reefs of the central Pacific is causing a systematic loss of benthic calcifiers, resulting in island-scale phase shifts to dominance by fleshy organisms. Despite the lack of macroalgal dominance at many of these islands it appears that coral reefs may be losing their capacity to actively build habitat and framework in the presence of local human populations.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1745, Hall D

Herbivory as a driving force in algal-coral phase shift event

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Short-spined black urchin *Anthocidaris crassispina is* a targeted economic species in Hong Kong. Local villagers harvest them for local consumption, or for use in more extensive farming for export. Tung Ping Chau (TPC), an island located in Northeastern Hong Kong, was designated as a marine park in 2001. Since then, harvesting of this sea urchin around this island has been restricted. When the harvesting pressure was released, the sea urchin density increased gradually since 2003, and urchins began to remove the previously extensive *Sargassum* bed on the southwest shore of the island, including Lung Lok Shui (LLS). We have monitored the densities of sea urchin and *Sargassum* in LLS before TPC became a marine park. A clear drop of *Sargassum* density was observed since 2006 as sea urchin populations bloomed. *Sargassum* completely disappeared in 2008, forming a new barren ground. Coral cover in LLS was very low (<5%). Coral recruitment was not observed in late 2009. However, in 2011, 2.93 recruits/m^2 were recorded, including *Oulastrea*, *Psammocora*, *Porites* and *Turbinaria*. These results suggest a potential phase-shift in the community structure of LLS, from being *Sargassum*-dominated to one that could be dominated by corals, if herbivory continues to keep the *Sargassum* density down. Continuous monitoring will be conducted to see if coral recruitment will continue to increase, or if these coral recruits could grow to dominate the benthic community. Herbivory could thus be the main driving force in this algal-coral phase shift event.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1715, Hall D

Long-term dynamics of a Tropical Eastern Pacific coral reef

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Coral reefs are highly dynamic systems that often exhibit natural cycles of decline and recovery after perturbations. However, anthropogenic impacts can upset such cycles and cause a shift from coral to algal dominated communities. A 13-yr-long study started in 1998 at La Azufrada coral reef in Gorgona Island, Colombia, a locality relatively free of human impacts. Results indicate that a dramatic decrease in coral cover occurred in shallow areas (from 61% in 1998 to 14% in 2007), with a concomitant increase in algal cover. In contrast, coral cover in deep areas has been high throughout the study (between 81% in 2002 and 64% in 2010). Differential coral mortality on shallow and deep areas has resulted from repeated aerial exposures of the reef during extreme low tides. While herbivore (sea urchin and fish) densities have been temporally variable, they have been significantly higher in shallow than in deep areas, and appear to be responsible for a sharp decline in turf and fleshy algal cover in shallow areas, and an increase in calcareous algae and coral cover since 2007. Thus, what appeared to be a major shift in this community, may be just a downward phase of a natural cycle.

11B Phase shifts & alternative states on coral reefs
Thursday 12 July, 1030, Hall D

11C Seaweed-coral competition

Coral-algae interactions in Singapore Reefs

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The persistent shift from a high abundance of hard corals to an algal-dominated system is one of the many signals of deterioration in reef health. A cascade of factors contribute to this 'phase shift', the relative importance of each differs among reefs depending on the environmental drivers that structure specific reef ecosystems. In Singapore, where high sediment loads in the water are a strong ecological driver of reef condition, reefs continue to thrive and maintain relatively high levels of biodiversity. In this study, coral-algae interactions were monitored quarterly for 2 years using permanent quadrats in 3 sites that demonstrate different impacts of macroalgae on corals. Coral-algae interactions varied between sites and quarters in terms of the frequency of the number of interactions and abundance of algae that interact with corals. Near-shore to off-shore patterns in the frequency of interactions was also observed. In 2010, thermal stress that caused bleaching at the onset of the southwest monsoon, followed by a severe storm event, influenced the outcome of observed interactions. Significant but weak correlations were found between coral-algae interactions and several water quality variables. An increase in coral mortality was noted after bleaching events although no significant differences were found in mortality indices among sites and sampling quarters. Our findings support observations on the role of perturbations and substratum availability in controlling abundance of corals and algae, and the importance of protecting ecosystem components that are critical for coral reef resilience.

11C Seaweed-coral competition
P109

Not all macroalgal dominated coral reefs are the same

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Macroalgal blooms reduce the economic, social and ecological value of coral reefs, increasingly motivating environmental management and conservation initiatives to identify indicators of the relative resilience of reefs. We aim to identify features of reefs and macroalgal communities that create different potential for macroalgal blooms. To do this we investigated the reported variation in algal community structures of degraded reefs. Subsequently, we distinguish reef habitats with regards to the type of macroalgal assemblage they are likely to support based on published knowledge, and interpretation of the processes that promote macroalgal growth. We continue to examine the traits of macroalgae in different communities, and identify how macroalgal assemblages combine impacts on the life cycles of other biota such as corals. We identified how, the implications of patterns in the presence and absence of macroalgal traits on different reefs to interactions for the survival of other benthic biota, can explain the stability of macroalgal dominance in these environments. Commonly reported macroalgae from degraded coral reefs such as *Sargassum* spp., *Lobophora* spp., and *Dictyota* spp., all differ in their potential impacts on benthic biota. Consequently we propose it is possible to rank the stability of degraded coral reef communities with regards to features of the macroalgal assemblages present and most likely to develop.

11C Seaweed-coral competition
Tuesday 10 July, 1000, Hall D

Frequency and dynamics of coral: macroalga interactions on Fijian reefs

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Coral reefs are degrading, with seaweeds commonly replacing corals. Seaweeds can affect corals in multiple ways, but some are allelopathic to corals upon contact. We assessed the frequency and dynamics of coral-macroalgal contacts on reefs in Fiji. Contacts were more abundant outside than inside multiple Marine Protected Areas. Visual damage to corals in contact with macroalgae varied with algal species. Corals contacting *Chlorodesmis fastigata* or *Galaxaura rugosa* showed bleaching or partial mortality, while corals contacting *Sargassum* and *Turbinaria* spp. showed no visual damage. A model based on coral and algal abundance at the field sites demonstrated that contacts between corals and the most harmful seaweeds were less frequent than expected, while contacts between corals and less harmful seaweeds occurred at expected frequencies. We examined the dynamics of contacts by transplanting *C. fastigata* and *G. rugosa* so that they contacted 20 colonies of 5 coral species for 7 weeks. *Acropora aspera* and *Pocillopora damicornis* were the most affected corals, while *Porites cyllindrica* and *Porites lobata* were most resilient. Coral size did not buffer against seaweed effects; seaweed damage to corals did not vary with coral size for any of the 10 coral-algal species pairs. We also assessed coral recovery by removing natural *Galaxaura* contacts with *P. damicornis* and *P. lobata*. All *P. lobata* colonies recovered within 2 weeks, but *P. damicornis* experienced minimal recovery, even after 5 weeks. These results highlight the species-specific effects of macroalgal-coral contacts and emphasize the importance of protecting reefs from macroalgal blooms to prevent phase shifts.

11C Seaweed-coral competition
Tuesday 10 July, 1200, Hall D

Coral recruitment on reefs with intact fish communities

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Coral recruitment is a key component of reef resilience, but our understanding of its contributions are limited in two ways. First, recruitment is usually sampled over short durations using fresh settlement tiles that avoid many of the important fine-scale ecological interactions, which develop over time to influence settlement, survivorship, and growth of recruits on reefs. Second, many recruitment studies are conducted on relatively degraded reefs, where certain ecological processes such as coral fecundity and grazing by herbivores may have been so diminished that recruitment processes may be operating in fundamentally different ways than on more pristine reefs. To address these issues, we conducted a four-year study of coral recruitment and related processes at the near pristine reefs of Palmyra Atoll in the central Pacific. Terracotta settlement tiles (n=180), situated at three locations and three depth zones across back and forereefs around the atoll, and repeatedly sampled in the lab and returned to the field, showed significant spatial heterogeneity in the development of fine-scale successional communities and rates of coral recruitment, survivorship, and growth. Additional short-term experiments, in which tiles were placed inside cages that excluded larger fishes, showed both transient increases in recruitment as well as increased mortality of recruits due to algal overgrowth. Further observations and analyses indicate the direct and indirect roles of grazing by parrotfishes and surgeonfishes in structuring benthic community dynamics. These results illustrate some of the complex interactions between fish, algae, encrusting invertebrates, and corals in early community succession in intact reef communities.

11C Seaweed-coral competition
Tuesday 10 July, 1015, Hall D

Experimental evaluation of the combined effects of macroalgae density and predation on coral growth

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Growing and severe anthropogenic forcing disturbs coral reef ecosystems. In Moorea, French Polynesia, macro-algal *Turbinaria ornata* overgrowth has been observed since the 80s. From a coral dominated reef, the ecosystem shifts to macro-algal dominance. The combined effect of different densities of *T. ornata* and predation (corallivorous) is assessed in the field on two coral species, *Acropora pulchra* and *Porites rus*, which have different sensitivities to disturbance. The combined effect of *T. ornata* and predation has a significant impact on the most vulnerable species, *A. pulchra*, whereas *P. rus*, is more robust, and shows no significant sensitivity to this combined effect. Predation dominates the macro-algal density effect inducing a negative growth rate for *A. pulchra* regardless of *T. ornata* density. Without predation and with a

maximal coverage, macro-algae affect coral growth rates. This threshold may be inducing a phase shift to macro-algal dominance. Differences in the response of the two coral species to the macro-algae-predation combined effect, suggest that they may be used as bioindicators of coral ecosystem health; the first as an indicator of a healthy ecosystem, the second as an indicator of a disturbed ecosystem.

11C Seaweed-coral competition
Tuesday 10 July, 1035, Hall D

Climatic thresholds to the persistence of seaweeds on coral reefs

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Large fleshy seaweeds of the genus *Sargassum* can create complex habitats comparable to that of reef-building corals, supporting a wealth of seaweed-dependent flora and fauna. However, recent examples of *Sargassum* overgrowth, which has smothered and killed stony corals on reefs around the world, have prompted the view that these fleshy seaweeds may be a major threat to coral reef biodiversity. Given that *Sargassum*-dominated patches often appear seasonally on and/or around healthy coral reefs, the question is what factors determine whether a *Sargassum* patch will persist while others decay? Although we are starting to realize the influence that herbivorous grazing can have on the distribution and persistence of seaweed biomass on coral reefs, our understanding of how climatic conditions can shape seaweed biomass has remained relatively poor. Using a functional approach, we documented the response of tropical *Sargassum* to seasonal and inter-annual variation in a range of climatic factors (temperature, light, water motion). We then explored how biophysical processes operating at the local scale (1–500 m), influenced the timing, size and distribution of *Sargassum*-dominated patches throughout the landscape (spanning 3–60 km distance) of both a fringing (Ningaloo Reef) and barrier reef (Great Barrier Reef) ecosystem. Here we present our landscape-scale biophysical model, and the new insights it provides into how present and future climatic conditions can influence the habitat dynamics and biodiversity of coral reef ecosystems.

11C Seaweed-coral competition
Tuesday 10 July, 1040, Hall D

Seaweed-coral interactions: direct versus indirect effects and can corals respond?

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We ask 1) do seaweeds damage corals indirectly via releasing dissolved organic carbon (DOC) that alters coral-microbe associations, or directly via transferring toxins following contact and 2) can corals induce resistance to allelopathic seaweeds? In previous tests of 4 corals contacting 8 seaweeds, we documented direct effects of lipid-soluble compounds for numerous interactions. However, the seaweed *Chlorodesmis* damaged *Acropora* beyond areas of direct contact, suggesting effects of water-soluble DOC, movement of lipid-soluble metabolites, or both. We conducted field assays to determine the effects of *Chlorodesmis* compounds dispersing through the water versus those needing direct contact, by placing *Chlorodesmis* and *Acropora* in direct contact or at equal distance but separated by a mesh preventing contact. *Chlorodesmis* harmed *Acropora* when in direct contact, but not if separated by 1-3 mm. Increasing algal abundance did not change this relationship. Corals were damaged only following direct contact. Effects were chemical, not physical because inert algal mimics had no effects whether in contact or not. In additional tests, brushing corals with *Chlorodesmis* (potentially transferring lipid-soluble compounds from seaweed surface) for only a few seconds a day caused bleaching and suppression of photosynthesis; brushing with inert mimics did not. However, corals induced greater resistance to *Chlorodesmis* when they are pre-exposed under natural or experimental conditions in the field. We demonstrate considerable damage to corals via seaweed lipids transferred on contact, can find no damage due to compounds transferred via the water, and note that corals may fight-back by inducing resistance to damage.

11C Seaweed-coral competition
Tuesday 10 July, 0945, Hall D

How much herbivory is sufficient to control macroalgae?

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It is well recognized that herbivores can prevent establishment of macroalgae that hinder the re-colonization of corals following a perturbation. An important but largely unanswered question is how much grazing is sufficient to control macroalgae. This

information is particularly important because human exploitation of herbivorous fishes has reduced their numbers and body sizes - and thus grazing intensity - on many tropical reefs worldwide. We explored the relationship between grazing intensity and macroalgae on reefs at Moorea, French Polynesia, following disturbances that drastically reduced the cover of live coral on the forereef. We undertook a field experiment where the number of visits by various sizes of herbivorous fish was manipulated to create a gradient in grazing intensity. Results indicate that even a relatively modest intensity of grazing by common parrotfishes and surgeonfishes prevented the establishment of macroalgae over a one year period. Substrate exposed to very low levels of grazing developed macroalgae, particularly species of *Sargassum* and *Turbinaria*. Additional field studies revealed that mature *Sargassum* was eaten by only a few, relatively uncommon species of fish grazers, while mature *Turbinaria* was almost entirely resistant to grazing. These findings highlight the need to understand the disparate functional roles played by different fish grazers on the reef in shaping resilience properties of the system.

11C Seaweed-coral competition
Tuesday 10 July, 1115, Hall D

Impact of macroalgal interactions on coral health across the USVI

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While competition between coral and macroalgae has been described as a fundamental process structuring reef communities, there is a lack of information on natural prevalence rates and species-specific impacts of competition on coral health. From 2008-2011, we conducted annual surveys of 24 study sites of the US Virgin Islands Territorial Coral Reef Monitoring Program (TCRMP) across a variety of depths (4-40 m) and distances from shore (0.1-18 km) in the U.S Virgin Islands. At each site we assessed benthic cover and coral health, including macroalgal interactions on each coral colony under the transects. The prevalence of coral-macroalgal interactions increased with macroalgal cover (r^2=0.23, p<0.001). The overall prevalence of macroalgal interactions was 41%; however, there was high species-specific variability, from 59% (*Montastraea annularis* species complex) to 17% (*Scolymia* spp.). The vast majority of macroalgae interactions (97%) were caused by the algal species *Lobophora variegata* (36%) and *Dictyota* spp. (61%). In addition, the extent of a colony affected by interactions was significantly greater for small colonies (<10 cm) than large colonies (df=118, p=0.0041). We are conducting a manipulative field experiment to test the hypotheses that the extent of macroalgal overgrowth and severity of negative health signs will be greater on smaller coral colonies (<10 cm) than larger colonies, and will differ between two susceptible species (*M. annularis* and *Porites astreoides*). We predict that larger colonies and the more robust species, *P. astreoides*, will have less negative health impacts.

11C Seaweed-coral competition
Tuesday 10 July, 1255, Hall D

Variation in elemental stoichiometry over four kingdoms of coral reef benthic organisms

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Variation in the ratio of elements is key to the biology and ecology of organisms. Phosphorus (P) is proposed to be important for growth because a large proportion of cell P is incorporated within RNA. We investigated variation in elemental stoichiometry and the relationship to RNA:DNA within tissues of representative genera of four dominant kingdoms of benthic coral reef organisms: corals, red, green and brown algae. Coral genera had higher % phosphorus (P), and lower carbon to P (C:P) ratio in tissues than all algal lineages, although % nitrogen (N) was not significantly different among lineages. Among the macroalgae, red and green lineages were similar but brown algae had lower %P and higher C:P ratios. Mean RNA:DNA ratio of tissues were similar among corals, red and green algae, but lower for brown algae. The variation of %P and RNA:DNA among genera within kingdoms was high and was associated with different traits for each kingdom grouping.

11C Seaweed-coral competition
Tuesday 10 July, 1245, Hall D

Coral physiological stress and recovery from invasive algal overgrowth

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The invasive red macroalga *Gracilaria salicornia* frequently overgrows coral and other benthic organisms in Hawaii, reaching biomasses nearing 20 kg dw m^{-2}. Dense mats can affect water motion, light penetration and bottom chemistry. As such, *G. salicornia* is a concern for reef managers, who require data on physiological impacts in order to develop and implement effective mitigation strategies. A field transplant study was performed to test for physiological stress impacts of *G. salicornia*

mats to the coral *Porites compressa*. Fragments of *P. compressa* were transplanted under 10 algal mats, with others maintained in 10 open reef reference pairs, along a 100 m transect on a reef in Kaneohe Bay, Hawaii. After 2 weeks the corals were removed and allowed to recover. Affected corals bleached, while the photosynthetic pigments chlorophyll *a*, c_2 and total carotenoids in remaining zooxanthellae increased, suggesting a shading stress response. Coral fragments under the algal mat also experienced elevated anaerobic respiration as measured by elevated lactate levels, likely in response to hypoxia associated with algal and community respiration. Oxidative damage, as measured by DNA damage, was not detected, suggesting the activation of protective biochemical responses in the corals. When the algal mat was removed, the coral recovered in 5 weeks, with affected parameters returning to reference levels. We have demonstrated that the effectiveness of management measures can be evaluated using physiological metrics and that *P. compressa* can likely recover from the overgrowth of *G. salicornia*, if the algal mats are removed.

11C Seaweed-coral competition
Tuesday 10 July, 1215, Hall D

Allelochemicals produced by Caribbean macroalgae can alter coral-microbial assemblages *in situ*

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Macroalgae are abundant competitors on coral reefs, especially where rates of herbivory are low and/or dissolved nutrients are high. This study investigated the impact of macroalgal allelochemicals on the structure of coral microbial assemblages. The effects of polar and non-polar macroalgal extracts were determined *in situ* using culture-independent methods. Crude extracts from three common Caribbean macroalgae were incorporated into stable gels at natural concentrations and applied directly to *Montastraea faveolata* and *Porites astreoides* corals on reefs in both Florida and Belize for ~72 hrs. Denaturing gradient gel electrophoresis (DGGE) of 16S rRNA gene amplicons was used to examine changes in the bacteria within the surface mucus layer (SML) of both coral species. Macroalgal extracts had no visible impact on experimental coral colonies, but most extracts induced a detectable shift in coral-bacterial assemblages. Some extracts were more potent, causing the assemblages on the entire colony to shift to a new microbial state (e.g. *Lobophora variegata*), whereas others had little to no impact (e.g. *Dictyota* sp.). These data increase our knowledge of the molecular interactions involved in coral-algal chemical ecology and lead to other testable hypotheses about the consequences of altering the natural state of coral microbial communities. It is unknown whether algal-mediated shifts may provide a competitive advantage to macroalgae and/or be detrimental to the coral host. As present-day reefs undergo phase-shifts to competitively dominant macroalgae that have potent biochemical defense mechanisms, we should question what effect they will have on overall reef health and physiology from a microbial perspective.

11C Seaweed-coral competition
Tuesday 10 July, 1130, Hall D

Contrasting competitiveness of Caribbean coral juveniles against a brown alga

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Macroalgae are known to reduce the survivorship and growth of juvenile corals through interference competition. However, there have been very few experimental studies testing the competition between juvenile corals and benthic algae. We experimentally investigated the competitiveness of 4 coral species at the juvenile stage (<40 mm in diameter) against the brown algae *Lobophora variegata* on a fringing reef in Curaçao, Southern Caribbean. This alga has increased in abundance on many degraded reefs and is thought to have deleterious effects on coral growth, recruitment and reproduction. Experimental transplantations of the alga around the periphery of coral colonies significantly reduced the overall growth of juvenile corals of *Agaricia agaricites*, but not of the other species (*Porites astreoides, Stephanocoenia michelinii* and *Siderastrea siderea*) in 1.5 mo. *A. agaricites* was the only species showing negative growth rates when in contact with the alga. These results match with the already demonstrated vulnerability of *A. agaricites* at the adult stage, and are concordant with a major decline in the abundance of juveniles between 1975 and 2005 for this species at nearby sites in Curaçao. Competition with algae can impact all stages of the coral life cycle, and could play a significant role in the changes that have occurred over the past 3 decades in the composition of juvenile coral communities.

11C Seaweed-coral competition
Tuesday 10 July, 1250, Hall D

Chemical warfare on reefs: macroalgae damage corals using surface-associated allelochemicals

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Over recent decades, many coral reefs have experienced phase-shifts from coral to macroalgae. These community transitions increase the frequency of algal-coral interactions on reefs, and such interactions could suppress the coral recovery and recruitment necessary to reverse phase-shifts. However, the extent to which macroalgae damage corals, the mechanisms involved, and the species-specificity of algal-coral interactions remain uncertain. Using field experiments we demonstrate that numerous macroalgae directly damage corals, and do so via hydrophobic allelochemicals present on algal surfaces. These hydrophobic molecules caused bleaching, decreased photosynthesis, and occasionally death of corals in 75% of the 32 interactions assayed (4 corals x 8 algae). Coral damage was generally limited to sites of algal contact, but algal photosynthesis was unaffected by coral contact. Artificial mimics for shading and abrasion did not damage corals and effects of hydrophobic surface extracts from macroalgae paralleled effects of whole algae, suggesting allelochemical over physical mechanisms were generating these localized effects. Rankings of macroalgae from most to least allelopathic were similar across the four coral genera tested. However, corals varied in susceptibility to allelopathic algae, with globally-declining corals like *Acropora* more strongly affected. Bioassay-guided fractionation of extracts from 2 allelopathic algae led to identification of 2 loliolide derivatives from the red alga *Galaxaura filamentosa* and 2 acetylated diterpenes from the green alga *Chlorodesmis fastigiata* as potent allelochemicals. These are the first identified allelochemicals that damage reef-building corals. Our results highlight a newly demonstrated, but potentially widespread, competitive mechanism to help explain the lack of coral recovery on many reefs.

11C Seaweed-coral competition
Tuesday 10 July, 0930, Hall D

Microbialization of coral reefs

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The decline of coral reefs is frequently correlated with local human activities. However, the mechanisms linking fishing, nutrient addition, and other stressors to coral decline are elusive. Our working hypothesis is that human activities alter the balance between reef-associated microbes and fish, specifically by altering the allocation of metabolic energy between the two communities. The main idea is that reduced grazing and/or nutrient enrichments increase algal release of dissolved organic carbon (DOC), which feeds the microbial communities. Rapidly growing microbial communities then overwhelm the corals as opportunistic diseases. This leads to a positive feedback system where more coral death leads to more space for algae, leading to more coral death, etc. Here we test this hypothesis using a combination of in situ experiments and large regional surveys. In the latter study, we surveyed microbial and fish sizes and abundances at 100 sites on 29 islands across the Pacific Ocean. Basal metabolic rates were calculated using established scaling relationships between organism size and basal metabolic rates. Microbialization scores (the percentage of the combined fish and microbial predicted metabolic rate that is microbial) were positively correlated with the NCEAS cumulative human impact scores. *In situ* experiments showed that some algal types (e.g., turfs) favored microbial growth and coral death. Combined, these findings support the hypothesis that human activities are increasing microbialization of reefs to the determent of corals.

11C Seaweed-coral competition
Tuesday 10 July, 1230, Hall D

Patterns of algae related coral mortality around Maui, Hawaii

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Long-term monitoring conducted by the Hawaii Coral Reef Assessment and Monitoring Program (CRAMP) and the Division of Aquatic Resources (DAR) shows up to 50% decreases in coral cover at observed reefs on Maui Island. Coral cover data collected at annual intervals are often used as an indicator of overall decline, but do not provide adequate resolution to make inference as to processes and causes of coral mortality. In 2009, colonies of the corals *Porites lobata* and *Montipora patula* were observed on a finer temporal scale at six sites, classified based on historical loses in coral cover, in order to describe potential causes of mortality at the colony level. Results showed that rates and causes of mortality did not vary significantly with site classification. However, site specific causes of mortality, including turf and macro-algal competition were

observed. In a second site-specific study at Kahekili Beach Park, Maui, colonies of the coral species *P. lobata* and *Porites compressa* were observed with greater spatial resolution, in order to determine whether mortality due to turf algal competition was ongoing and/or more prevalent in areas with historical degradation, or proximity to nutrient rich effluent seeps from nearby injection wells. Preliminary results indicate that algal competition is the main cause of mortality and tends to occur at higher rates in areas with historical losses of coral cover.

11C Seaweed-coral competition
Tuesday 10 July, 1030, Hall D

Contact with seaweeds enhances corallivory on scleractinian corals

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Under normal circumstances, corallivorous invertebrates are a minor component of the predator guild on coral reefs. In the Caribbean, they have never been thought of as being a significant cause of coral mortality. We observed a large abundance of the corallivorous fireworm *Hermodice carunculata* in clumps of *Halimeda opuntia*, in contact with corals in Curaçao, southern Caribbean. *H. carunculata* is known as vector for the bleaching pathogen *V. shiloi* in scleractinian corals and thus could also be implicated in the spread of coral diseases in the Caribbean. We hypothesized that *H. opuntia* provides shelter for invertebrate corallivores such as *H. carunculata* which can lead to increased corallivory and potentially a faster spread of coral diseases. In an in situ transplantation experiment of *H. opuntia* clumps on corals, coral tissue mortality was higher in contact with clumps left untouched, compared with clumps from which all corallivores were periodically removed. Tissue loss was positively associated with the number of *H. carunculata* fireworms found in each clump at the end of the experiment. We further tested the factorial effects of *H. opuntia* and two corallivores (*H. carunculata* and the snail *Coralliophila abbreviata*) on coral mortality under laboratory conditions. Coral mortality occurred in the presence of algae, but this mortality was greatly enhanced when fireworms were added. In contrast, *C. abbreviata* showed no additive effect. We conclude that corallivory, combined with increased algal abundance, could result in significant coral mortality, further reinforcing the need to reduce macroalgal abundance on reefs.

11C Seaweed-coral competition
Tuesday 10 July, 1145, Hall D

11D The boom & bust of urchins & starfish

Sea urchins dynamics in subtropical Brazilian rocky reefs

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Sea urchins can play a vital role as habitat engineers in temperate and tropical reefs, by controlling macro-algal cover and acting on the maintenance of, and transition between stable states. Despite the abundance of urchins on Southwestern Atlantic rocky reefs, the functional role of these sea urchins remains to be evaluated. On subtropical reefs of the Brazilian coast (22°59'S, 41°59'W), we applied a two pronged approach: evaluation of the spatial distribution of the sea urchin assemblage, and exclusion experiments. At each depth (1 m intervals), the distribution of urchin species were assessed using quadrat counts, while benthic cover and substrate complexity were evaluated using video-transects. Cages were installed at depths with higher densities of urchins. Abundance estimates indicated a spatial segregation among the 7 species detected. *Echinometra lucunter* dominates the first 3 meters, *Paracentrotus guaimardi* is more prominent at mid depths (4 to 7m), and *Lytechinus variegatus* is the most common species below 8 meters depth. Exclusion of urchins was followed by a slow transition from crustose coralline algae to an articulated coralline algal cover. As an ecosystem engineer, only adult specimens (>5 cm) of *E. lucunter* is associated with the formation of barren patches. The second most abundant species (*P. guaimardi*), even when found at similar densities and biomass as *E. lucunter*, was not associated with the formation of barren habitats, probably due to the lack of aggregation of adults. Data analyzed suggest that *E. lucunter* is a potentially key species on Brazilian subtropical rocky reefs, and it seems to have no functional counterpart among its co-occurring species.

11D The boom & bust of urchins and starfish
Wednesday 11 July, 1730, Hall D

Algal growth and coral recruitment: distinguishing fish and urchin effects

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Fishes and urchins are both important herbivores on coral reefs, enhancing reef resilience and resisting coral-macroalgal phase shifts, but the relative importance of these herbivore guilds is poorly understood. We conducted a 2 x 2 factorial field experiment to quantify effects of herbivorous fishes (mainly parrotfishes and surgeonfishes) and urchins (*Echinometra mathaei*) on macroalgal growth and coral recruitment on Midway Atoll, a long-protected Northwestern Hawaiian Island reef with abundant urchins and largely intact fish assemblages. We measured algal growth and coral recruitment over 10-11 months on ceramic tiles that were uncaged, partially caged, fully caged, or fully caged and enclosing urchins, to provide all possible urchin-fish combinations. Fish grazing effectively limited algal biomass (37.7 ± 5.5 g wet wt. per tile); biomass was 66 times higher on tiles exposed only to urchins (2502.4 ± 248.8 g) and 182 times higher on tiles with no grazers (6845.3 ± 282.5g). Herbivorous fishes apparently have a strong positive but indirect effect on coral recruitment by reducing algal growth: recruitment was more than twice as high in both treatments exposed to fishes than in treatments with only urchins or no grazers, indicating that algae are a greater inhibiter of coral recruitment than fish grazing. Because algal biomass was negatively correlated with coral recruitment (r^2=0.157, p<0.001), management to increase herbivorous fishes and grazing levels is likely to benefit coral recruitment. This study underscores the importance of herbivorous fishes in removing macroalgae, promoting coral recruitment, and enhancing reef resilience.

11D The boom & bust of urchins and starfish
Wednesday 11 July, 1715, Hall D

***Acanthaster planci*: the hunt for prey corals drives the movement of predator seastars during outbreaks**

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Outbreaks of the coral predator starfish *Acanthaster planci* (crown-of-thorns) are devastating disturbances that decimate corals and severely impact reef communities in many regions throughout the Indo-Pacific. While several studies have reported the large scale impacts of this predator during outbreaks, few have explored the detailed course of these events, and particularly the processes that drive the propagation of seastar densities, and their consequences on coral communities within reef ecosystems. Recently, an outbreak of this starfish has affected the coral reefs around the island of Moorea, French Polynesia, where it has progressively but severely depleted coral populations: from ~50% to <5% live coral cover in few years. Based on a multi-scale survey of reef communities around this island, we quantified the dynamics of *Acanthaster* aggregations over the whole process of this event and evaluated its impacts on coral and associated communities. The *Acanthaster* outbreak constituted a relatively slow and diffusive disturbance that originated in a restricted source area at the bottom of the outer reef slope and progressively spread to adjacent localities by migration of starfish individuals in aggregative waves, until it affected the whole island. *Acanthaster* densities affected coral dynamics in a similar pattern at each impacted reef location, where this predator depleted live coral cover by sequentially decimating coral populations following its feeding preferences. By the end of the outbreak, predation by *Acanthaster* has resulted in large-scale devastation of corals around Moorea, and a strong impact on other reef communities such as algae and corallivores.

11D The boom & bust of urchins and starfish
Wednesday 11 July, 1700, Hall D

Functional diversity of herbivorous urchins in Maui, Hawai'i

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Grazing by herbivorous urchins is known to be important to the health and persistence of coral reef ecosystems. However, much of what we understand about urchin-reef interactions has been derived by studying few urchin species in a limited number of marine ecosystems. Here, we explored the functional diversity of herbivorous urchins in a near-shore coral ecosystem (Kahekili Herbivore Fishery Management Area) in Maui, Hawaii. First, we used field-based grazing assays to compare dietary preferences and grazing rates among 5 urchin taxa common to reefs along leeward Maui. Urchins were offered 6 algal types including: *Turbinaria ornata* (brown macroalga), *Ulva fasciata* (green macroalga), *Acanthophora specifera* (red macroalga; invasive), *Amansia glommerata* (red macroalga; native), mixed turf (fleshy algae <1 cm on carbonate), and CCA (crustose coralline algae on carbonate). Second, we deployed a long-term caging experiment on reef isolates to examine the functional roles of 3 urchin species common in the region (*Heterocentrotus mammillatus, Echinothrix calamaris*, and *Tripneustes gratilla*). Isolates were caged using 3 cm black plastic mesh and urchins added at densities of 2 urchins per m^2 in both monocultures and all possible 2-sp. combinations. Changes in the % cover, density, and composition of benthic

organisms were compared among urchin treatments and to full exclosures and open plots, to explore any differential impacts among urchin taxa (and combinations) on benthic communities. Results of this work will be used to explore functional diversity among Hawaii's urchins, and the relative importance of each species to the functioning of Hawaii's coral reefs.

11D The boom & bust of urchins and starfish
Wednesday 11 July, 1750, Hall D

Can marine protected areas help stall crown-of-thorns starfish outbreaks?

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A key management question is whether the establishment of Marine Protected Areas (MPAs) in the Great Barrier Reef (GBR), in particular 'green zones' closed to fishing, can be effective in keeping populations of crown-of-thorns starfish (COTS) in check by supporting suitably high densities of COTS predators. The COTS feeds on coral polyps and is the single most important cause of loss of coral cover. This is particularly true for the GBR where outbreaks have followed approximately 15 year cycles. The COTS have a density threshold of 10 COTS Ha^{-1} for outbreaks, beyond which they reduce coral cover at a higher rate than corals recruit and grow. We developed a Model of Intermediate Complexity for Ecosystem assessments (MICE) to simulate the predator-prey dynamics of coral, COTS, and COTS predators, and the role of MPAs in maintaining populations below the outbreak threshold. The COTS population dynamics are modelled using an age-structured model which assumes there are different predation risks for juveniles and adults. The coral population dynamics distinguish two classes of corals (fast-growing and massive corals). Delay-difference models are used for three classes of predators: small fish, large fish and triton shells, and include the effects of fishing. The model is fitted to available data and we start with few crucial interactions, foreseeing to add (or not) complexity as the model fails (or not) to reproduce reality. This version of the model considers single reefs in isolation but future work will aim to incorporate spatial structure, including connectivity among reefs.

11D The boom & bust of urchins and starfish
Wednesday 11 July, 1645, Hall D

The effectiveness of *Diadema* in triggering a phase shift reversal

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The degradation of coral reefs in the Caribbean was exacerbated following the decline of *Diadema antillarum* populations in 1983 due to an unknown disease. This led to what is now commonly referred to as a 'phase shift' on coral reefs, in which reefs move from a coral dominated state to an algal dominated state. *Diadema* is considered a keystone grazer on Caribbean coral reefs because of the impact that their removal or decline in numbers has on coral reefs. As *Diadema* populations decreased after 1983, fleshy macroalgae increased significantly. Essentially, this served as the tipping point of a phase shift on Caribbean reefs. We believe *Diadema* has the potential to play a pivotal role in the reversal of phase shifts on these reefs. Students and faculty from the Department of Biology, Ecology and Conservation at St. Georges University together with staff from the Moliniere Beausejour MPA reintroduced *Diadema* on an algal dominated reef in Grenada to assess their role and effectiveness in triggering a phase shift reversal on that reef. *Diadema* were reintroduced into a 10 x 10 meter plot on an algal dominated reef within the Moliniere Beausejour MPA in Grenada and the benthic composition of that plot was monitored over time. Following the reintroduction of *Diadema* to the plot area, there was a decrease in fleshy macroalgae and an increase in live coral, bare substrate and coralline algae. The recorded changes in benthic composition following the reintroduction of *Diadema* revealed early signs of a phase shift reversal.

11D The boom & bust of urchins and starfish
Wednesday 11 July, 1745, Hall D

Mortality of the Sea Urchin *Diadema setosum* affected by low salinity in the Inner Gulf of Thailand

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A long-term coral reef monitoring program at Khang Khao Island, Chonburi Province in the inner Gulf of Thailand has been carried out since 2007. The survey in March 2009 showed that the average population density of the sea urchin *Diadema setosum* was 14.0 ± 1.1 individuals/m^{-2}. The elevated seawater temperatures in 2010 caused the mass coral bleaching in the Gulf of Thailand but the

population density of *D. setosum* (surveyed in July 2010) was maintained, 16.0 ± 1.0 individuals/m^{-2}. Densities of *D. setosum* in September 2010 and August 2011 had dramatically decreased, 9.5 ± 0.8 individuals/m^{-2} for the former and 5.2 ± 1.4 individuals/m^{-2} for the latter. The survey in August 2011 showed that salinity of the upper water layer dropped to 10.1 psu while salinity of the lower water layer was 23.1 psu. The low salinity also caused mass coral bleaching around Khang Khao Island, especially the corals *Pocillopora damicornis* and *Acropora* spp., and had impacts on bivalves, such as *Spondylus* cf. *versicolor* and sea cucumbers. This study suggests that the long-term population maintenance of *D. setosum* and other reef associated fauna depends on frequency and severity of multiple disturbances. The impacts of low salinity on coral communities in the Gulf of Thailand should be studied in detail to improve our understanding of coral reef ecosystems.

11D The boom & bust of urchins and starfish
P110

Sea urchins and their predators on the Great Barrier Reef

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We employed a combination of surveys and a non-invasive tethering technique, to examine diel predation patterns on sea urchins in an intact coral reef system on the Great Barrier Reef (GBR). Surveys revealed that sea urchins were active and exposed at night. *Echinometra mathaei* and *Echinothrix calamaris* were the most abundant species with significantly higher night densities (0.21 and 0.03 ind. m^{-2}, respectively), than daytime densities (0.05 and 0.001, respectively). Bioassays revealed that exposed adult *E. mathaei* (the most abundant sea urchin species) were 30.8 times more likely to be eaten during the day than at night. This observation concurs with widely held assumptions that nocturnal activity is a risk-related adaptive response to diurnal predation pressure. Despite relatively intact predator communities on the GBR, predation pressure on diurnally exposed *E. mathaei* assays was highly variable at a local scale. Underwater video cameras recorded four potential fish predators of tethered adult sea urchins (*Balistoides viridescens*, *Balistapus undulatus*, *Lethrinus atkinsoni*, and *Choerodon schoenleinii*). *Balistoides viridescens* handled *E. mathaei* significantly faster (mean 0.7 min) than B. undulatus (5.2 min), and successfully preyed on 77% of detections compared to just 17% for *B. undulatus*. Additionally, *B. viridescens* were behaviourally dominant among fish predator species. *Balistoides viridescens* and *B. undulatus* both appear to play an important role as predators of sea urchins on the coral reefs of Lizard Island, highlighting the potential significance of these relatively rare but functionally important species.

11D The boom & bust of urchins and starfish
Wednesday 11 July, 1630, Hall D

11E Long-term change in coral reef ecosystems

Increased coral recruitment after disturbances at Moorea, French Polynesia

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Coral assemblages at Moorea, French Polynesia, have been impacted by numerous large-scale disturbances over the last three decades, but have shown a remarkable capacity to recover from these acute and recurrent stressors. However, the ecological resilience in terms of overall coral cover was associated with a shift in the structure of the assemblages. Recently, corals of the outer slopes underwent two major disturbances - an *Acanthaster planci* outbreak beginning late 2006 and cyclone Oli in February 2010. Impacts of these disturbances on coral population dynamics were assessed through the monitoring of recruit (< 3 month old), juvenile (1 to 4 year old) and adult abundance over 9 years (2003-2011) at 9 stations (3 locations and 3 depths). Results demonstrate spatial variability in the impact of disturbances among sites and depths. Among the dominant genera, *Acropora* was the most impacted, followed by *Pocillopora* and *Porites*. The impact of the two disturbances was much higher on adults than on juveniles; adult abundance was reduced by one order of magnitude, while juvenile abundance showed a milder 60% decrease from 2003 to 2010. Interannual variation in recruit densities was not related to disturbances. Recruit and juvenile abundance showed the highest values ever recorded at Moorea during the last survey in 2011. This demonstrates that despite a catastrophic drop in adult abundance and cover, coral assemblages at Moorea have not lost their capacity to recover through recruitment, which appears to be a key process supporting the high resilience of this system.

11E Long-term change in coral reef ecosystems
P111

Anthropogenic mortality on Caribbean coral reefs before coral bleaching and disease

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Caribbean reef corals have declined precipitously since the 1980s due to bleaching, disease, and overgrowth by seaweeds, but the extent of earlier degradation due to overfishing and land clearing is controversial. To help resolve this issue, we sampled intact coral and mollusk death assemblages from Bocas del Toro, Panama and reconstructed a timeline of ecological change extending from the 19th century to the present. Large changes were observed before 1960 in coastal lagoons in conjunction with major land clearing activities, and after 1960 offshore. Striking changes include the demise of the previously dominant staghorn coral *Acropora cervicornis* and the oyster *Dendrostrea frons* that lives attached to gorgonians and staghorn corals. Reductions in bivalve size and simplification of gastropod trophic structure further implicate increasing environmental stress. Our results reveal that Caribbean reef degradation began decades before outbreaks of coral bleaching or disease.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1400, Hall D

Measuring coral community resilience: a 40-year analysis at Andros Island

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Understanding the contribution of coral resilience, herbivory, and disturbance in structuring present-day Caribbean coral communities is hindered by the lack of datasets encompassing the time-scales of recent decline. In a partnership between the University of Miami and the US Navy's coral reef monitoring program at the Atlantic Undersea Test and Evaluation Center (AUTEC), coral reef health and drivers of change were examined over 40 years using novel image mosaicing tools, and a unique 40+ year dataset of coral health and community composition from Andros Island, Bahamas. At Andros, reef decline was found to be a-typical; coral morality and disease increased significantly between 1970 and 2000, whereas macroalgal cover did not. Lacking evidence of a coral-macroalgal phase shift on Andros Island reefs, bleaching and disease events were identified as the primary drivers of coral mortality since 1968. As a result, coral cover declined for 80% of coral species surveyed, and species richness dropped from 24 to 17 species at fixed sites. Of the 24 coral species studied, only 3, (*Siderastrea siderea*, *Montastraea cavernosa*, and *Porites astreoides)* were resistant to recent decades of disturbance, whereas 1 species (*Porites porites*) was found to be resilient. These results show that in the absence of phase-shifts, bleaching and disease events can cause significant changes to benthic coral communities and that herbivory-based management may be insufficient to promote coral health and recovery. These results underscore the need to understand and regulate coral bleaching and disease events for reversing recent decades of coral community decline.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1130, Hall D

Reef collapse but little coral diversity loss over 50 years

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The Grand Récif of Toliara (GRT) lies on the West coast of Madagascar at latitude 23°S, within the southwestern Indian Ocean biodiversity hotspot. Scleractinia diversity, described in detail between 1961-71, was re-evaluated in 2009, revisiting most of reef zones and habitats studied almost 50 years earlier. Today, the GRT is severely degraded and characterized by low coral cover, high biomass of macroalgae, and low reef fish biomass. Changes were most profound on the shallow reef flats where a generalized loss of coral cover (currently 2%) reflects the deeply modified geomorphology of this zone. Here, coral diversity is <30 species per habitat, but the Grande Vasque (an almost enclosed small lagoon) is still an oasis of coral diversity (>80 species) rimmed by dense *Acropora* stands. Inner reef slopes that harboured the highest diversity in the 1960s still maintain rich coral communities of more than 80 scleractinian species, clustered in small patches, but

representing merely 5% coverage. Diverse pocilloporids and acroporids still characterize the upper outer reef slopes, reaching 30% cover, but they are replaced locally by 95% macroalgae. Lower slopes contained more diverse coral communities. Surprisingly, the phase shift from corals to macroalgae on the GRT is not hitherto accompanied by a significant loss in coral diversity. *Alveopora* and *Gyrosmilia* are the only genera, abundant in the 60s, that seem to have disappeared from the revisited sites.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1115, Hall D

Disparate trajectories of coral reef decline inform strategies for recovery

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Recent meta-analyses document dire trends of regional coral reef decline that obscure widely disparate histories of local reef ecosystems that in turn offer important clues for more effective conservation and governance. The IUCN Coral Reef Resilience Project is compiling high quality quantitative survey data from coral reefs worldwide to document geographic and temporal variability in the status and trends of coral reef ecosystems. Our goal is to evaluate the extent to which local protection from human impacts may have conferred increased resistance to climate change or the potential for reef recovery following severe mortality due to natural or human disturbance. Work so far based on more than 60 data sets from 50 localities throughout the wider Caribbean has revealed striking and persistent local differences in live coral cover over the past 30 to 40 years. Quantitative paleontological surveys have revealed additional large but highly variable reductions in principally acroporid corals due to intensive land clearing and agriculture as early as 1900. All reefs exhibit significant declines in live coral cover but their timing and magnitude vary several fold among localities and environments with strikingly lower declines with increasing depth. Fish, sea urchins, and macroalgae exhibit even greater local and environmental differences in abundance and decline, most of which can be readily attributed to differences in local exploitation, pollution, and extreme climate events. Not all coral reefs are on the slippery slope to slime and understanding why may make an enormous difference in their survival.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1230, Hall D

Long term spatio-temporal patterns in benthic composition of Caribbean coral reefs

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We examine spatial patterns and temporal trends in several metrics of benthic composition, within nearshore ecosystems in St. Croix, U.S. Virgin Islands (St. Croix and St. John) and southwest Puerto Rico. These ecosystems comprise inter-connected habitats including mangrove forests, seagrass beds, unconsolidated sediments, and coral reefs and hard-bottom substrates, all of which provide shelter and sustenance for fishes and invertebrates that form the basis of important fisheries in the Caribbean. Broad-scale characterization through mapping and in situ surveys of these habitats from 2001 to 2011 have revealed complex spatial and temporal patterns in benthic composition that often correlated and influenced the distribution and abundance of fish and invertebrate populations. Depth and rugosity of substrates correlated positively with coral cover and taxa richness, and influenced the abundance and size-class structure of several fish species. Other measures of benthic composition were also useful in Maxent predictions of potential occurrence, and size-class distribution of scarid assemblages. In addition, the percent cover of live coral has chronically decreased over time suggesting that habitat quality may be declining as well. Our benthic characterizations provide the basis for identifying species-habitat relationships, increase our understanding of spatial patterns in the distributions of habitats, and illustrate important and crucial linkages for the successful management of coral reef fisheries and other important marine resources.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1445, Hall D

Re-assembly schedules for Great Barrier Reef coral communities following disturbance

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One characteristic of a resilient coral reef community is that it recovers swiftly to its pre-disturbance state. Conversely, a substantial shift in the species composition of a recovering community may indicate a shift in ecosystem health and function. Using a long-term data set, I selected coral communities that lost at least 33% of pre-existing coral cover due to disturbance, but then regained at least 50% of

the coral cover lost. Similarity indices were used to compare progressive assemblage changes during the recovery period. Further, I contrasted these assemblage changes with those of coral communities that had comparatively poor recovery of coral cover over a similar recovery time frame. Coral communities that were affected by a single disturbance type were likely to regain their pre-disturbance composition in 7 years or less. Communities that suffered multiple disturbance types, either at once or sequentially, were likely to take 9-27 years. The communities that re-assembled relatively rapidly occurred on mid-shelf reefs across a range of latitudes, and re-assembly was driven by recovery of tabulate *Acropora* spp. Communities that were affected by disturbances of multiple types re-assembled slowly regardless of location, pre-disturbance composition or the magnitude of change in the assemblage. Coral communities that suffer multiple disturbance types are likely to be more susceptible to coral-algal phase-shifts, particularly if disturbance intervals and, therefore, recovery phases also become shorter.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1200, Hall D

Historical recoveries in Hawaiian coral reefs: Understanding long-term social-ecological linkages

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Coral reef ecosystems are declining worldwide, yet regional differences in the trajectories, timing and extent of degradation, highlight the need for in-depth regional case studies to understand the factors that contribute to either ecosystem resilience and sustainability, or decline and collapse. We reconstructed long-term social-ecological interactions in Hawaiian coral reef environments over 700 years using detailed datasets on ecological conditions, proximate anthropogenic stressor regimes and social change. Here we report novel recovery periods in Hawaiian coral reefs attributed to a complex set of historical events and social factors operating at the underlying level, which served to release reefs from human stressor regimes at the proximate level. Recovery at the ecosystem level is associated with reductions in anthropogenic stressors over long time periods (decades+) and large spatial scales (>103 km^2). Social factors associated with ecosystem recovery include ecosystem protections, depopulation, transformation in human institutions for coral reef management and changing economies and modes of production. Our results challenge conventional assumptions and reported findings that human impacts to ecosystems are cumulative, and lead only to long-term trajectories of environmental decline. In contrast, recovery periods reveal that human societies have interacted sustainably with coral reef environments over long time periods, and that degraded ecosystems may still retain the adaptive capacity to be resilient to human impacts. The ability of human societies to adapt to environmental challenges in the past provides promise for contemporary efforts to manage ecosystems and societies toward social-ecological sustainability.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1015, Hall D

Long-term changes of coral reefs in Kenting National Park, Taiwan

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In this study, temporal change of coral reefs was analyzed through re-examination of historical studies (1987 and 1999) and comparison with recent data (2003-2010) for four sites along the coast of Hengchun Peninsula (Kenting National Park, Southern Taiwan). In general, coral cover decreased from 44% (1987) to 35% (1999), and recovered to 43% (2009), followed by a significant decline to 25% (2010) due to the passage of the typhoon Morakot in August 2009. Changes of coral community composition varied at each reef. The coral community in Wanlitung declined then recovered through time, with a switch in the dominant functional group composition from *Acropora* spp. towards stress-tolerant species mainly composed of *Porites* spp. At Hongchai, less than 3 km away, the coral community declined and never recovered. In Siangjiao Bay, the coral community, originaly dominated by massive and foliaceous corals, was stable until the severe physical damage of the typhoon in 2009. The coral community in Leidashih, dominated by soft coral had the most stable community in Kenting National Park. Our analyses suggest that: (1) decreases in stress sensitive species such as *Acropora* spp., may be compensated for in terms of coral cover, by

an increase in other stress tolerant species; (2) the loss of a fundamental functional group showed the absence of resilience of these reefs after multiple disturbances; (3) coral cover should not be the only parameter to define resilience ability and there is an urgent need to identify mechanisms determining changes in coral community.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1430, Hall D

Half a millennium of coral reef fisheries in Hawai'i and Florida

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Coral reef fisheries have been overexploited around the world, resulting in ecosystem declines and food security risks. Fishing in reef environments has been ongoing for centuries, but rates of sustainable fishing are based primarily on short-term observations. Here, we reconstruct fisheries yields for coral reef ecosystems for the entire period of human habitation, for both the Florida Keys and the main Hawaiian Islands, the two largest coral reef ecosystems under US jurisdiction. This involved a mixed methods approach, in which we estimated yield by fishery sector (commercial, subsistence, recreational and aquaculture) over the past 5 to 7 centuries. We found substantial differences in historical yields between the 2 locations, with Hawai'i sustaining yields of more than 12 metric tonnes per km^2 for four centuries prior to the arrival of Europeans. This period was characterized by adaptive management strategies that effectively protected reef habitat, vulnerable life history stages for fish, and species with a high susceptibility to overfishing. Reefs in both Florida and Hawai'i were intensively exploited after European contact, with sequential export-driven depletion evident in Florida over the past century. Today, both exhibit strikingly similar modern catch levels, with landings exceeding 10 MT km^2, and evidence of overfishing. These results suggest that a precedent exists for successful management of coral reef fisheries in the past, and that robust social institutions and management strategies can increase and sustain long-term yields from coral reef fisheries.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1000, Hall D

Thirty years of change in Florida Keys reef fish communities

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The reefs of the Florida Keys are home to a suite of ecologically and economically important communities, but these communities have been dramatically altered by human activities. Historical data documented declines in trophy fish size that occurred 30-50 years ago, but these datasets lack spatial and temporal resolution. As the management focus in marine systems shifts to ecosystem-based management, more precise data on the status and trends of these communities are needed. We use data from the long-term reef visual census reef fish monitoring program, one of the longest continuous monitoring programs for marine systems, to examine trends and changes in reef fish communities over the past 30+ years. We found a variety of trajectories for different species and functional groups, including dramatic increases and decreases in abundance. Despite the variety of single-species patterns, multivariate analyses shows that reef fish communities have been changing in a clear and consistent manner over the past 30 years. However, the timing of changes in single-species patterns suggests that multiple factors are driving community change, including loss of live coral and decline of species dependent on live coral habitat, and slight recovery of the most heavily targeted fishery species, likely resulting from the combination of MPAs and increased regulations. Despite the increase in abundance of some commercial species, broad community metrics suggest that the Florida Keys is still a heavily exploited ecosystem that will require significant changes in management and a long time frame to restore reef fish communities.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1030, Hall D

Spatial and temporal coral mortality on the Great Barrier Reef

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Disturbances on coral reefs are predicted to increase as a result of global warming, however, the effect of disturbance on coral population dynamics remains poorly understood. This study quantified mortality of *Acropora millepora* at 3 locations (2 sites each) along the Great Barrier Reef, between April 2009 and April 2011. Sampling was conducted four times in the first year, and half-yearly in subsequent year. Contrary to prevailing theories, neither whole-colony nor partial-colony mortality rates were related to colony size. Partial-mortality rates varied seasonally, and were generally higher at most sites during

the summer months (between December and April), possibly reflecting stress associated with warmer water and high light levels. During the first year, 20% of tagged colonies died; whole-colony mortality increased by over 2-fold to 70% in the second year. High whole-colony mortality was the result of 5 of the 6 sites being affected by acute disturbances: Cyclone Ului in Whitsundays (March 2010), flooding of the Fitzoy River in the Keppels (January 2011) and Cyclone Yasi in the Palms (February 2011). Whole-colony mortality was patchy and often severe. For example, category 3 Cyclone Ului killed 75% of tagged colonies at Hook Island, but no whole colonies were killed at Mid-Molle Island just 3km away. The flooding of Fitzroy River killed all 60 tagged coral colonies in the Keppels. These results indicate that acute disturbance destroyed much more tissue that chronic stressors. If acute disturbances increase as a result of climate change, coral population dynamics are likely to be vastly altered.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1415, Hall D

Reassembly of an isolated coral reef fish community following severe disturbance

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With numerous ecosystems now exhibiting marked responses to a warming and more variable climate, a major challenge for ecology is to understand the many competing mechanisms that determine population change and alter community structure. Coral reef fishes play a fundamental role in maintaining ecological processes in reef ecosystems, while the removal of apex predators of reefs can also have significant effects on reef fish assemblage structure. The Australian Institute of Marine Science (AIMS) has monitored fish and benthic communities at an isolated oceanic atoll reef system in the north-east Indian Ocean (Scott Reefs) since 1994. This provided a unique opportunity to examine the resilience, recovery and restructuring of reef fish communities at decadal scales, after widespread disturbance events involving both coral bleaching and cyclonic storms, each overlaid on a reef system subjected to high levels of fishing for sharks. The fish community at this important reef system has undergone significant change in composition through this 17 year period, and is now quite different to the assemblage that occurred on the reef prior to the 1998 bleaching. Fish assemblages on the reef have undergone two sequential phases since the intact community dominated by habitat and dietary specialists. The intermediate phase was characterised by species associated with habitat types arising from erosion of dead coral, while the recent phase is characterised by species with generalist diet and habitat requirements with an overarching increase in mid-sized carnivorous species, presumably due to the reduction of their main predators through the fishing of sharks.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1145, Hall D

Restrained recovery of coral; the influence of macroalgae and MPAs

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The fringing reefs of the inner Seychelles suffered extensive coral mortality in the wake of the 1998 bleaching event. In this study we use a long term dataset (1994-2011) to evaluate the interplay of management status, habitat, post-disturbance coral cover and change in macroalgal cover, to predict coral recovery. Coral recovery is occurring in all habitats, but is highly variable among sites and times; between 2005 and 2011 the increase in coral cover averaged 1% per annum across all sites, with a maximum increase of 4% per annum at sites showing strong recovery. However, mean coral cover across the study area remains at half of 1994 levels (14%). Marine Protected Areas (MPAs) were associated with significant coral recovery, but only where cover of macroalgae is low and has not increased over time. MPAs where macroalgae cover has expanded since 1998 show negligible recovery despite increases in herbivorous fish biomass. Terrestrial-derived nutrient input is identified as a potential chronic stressor, likely to have increased macroalgal cover and impeded coral recovery. Where coral is recovering, there has been a shift in relative prevalence of colony lifeform from branching to encrusting species, mediated by habitat. This may have significant long term consequences for associated reef fauna through loss of complex reef structure, even if pre-disturbance levels of coral cover are attained. Management actions incorporating coastal and terrestrial systems, and addressing herbivore community composition would complement the establishment of MPAs, and are needed to address phase shift reversal.

11E Long-term change in coral reef ecosystems
Friday 13 July, 1215, Hall D

Theme 12. Life histories & reproduction

12A Life histories & reproduction

The fastest fish in the world to change colour

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The animal world abounds with conspicuously colourful displays and appearances, with functions to attract or repel, depending on circumstance. While the fur- and feather-based colorations of mammals and birds are rather inflexible short-term, animals like fishes, frogs, reptiles and octopuses can change colour relatively quickly. They can do so because their coloration is regulated by pigments and reflecting structures in their skin cells. Such a capacity allows reef fish, for instance, to display brilliant colours when needed, like during courtship, but to take on a drab appearance when facing danger. Anecdotal reports suggest that colour modification to match short-term changes in social and ecological environment is widespread among fishes on coral reefs. However, surprisingly little has been known about how quick such colour change can be, which is obviously important for the ability of fish to adapt. We found that the damselfish *Chrysiptera cyanea* typically changes from a brilliant electric blue to a blackish-violet appearance typically within 2-4 s, and at the very extreme in 0.5 s. The change from black to blue was faster than the other way round, and males changed colour more quickly than females, both of which makes sense in light of the species' mating behaviour. The speed of the colour change was faster than hitherto thought physiologically possible for fish, and makes *C. cyanea* the fastest fish in the world to change colour.

12A Life histories & reproduction
Friday 13 July, 1215, Sebel Bluewater

Reproduction in corals at the individual and modular levels

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Reproductive studies on corals are usually based on samples collected regularly from different colonies over a period of time. Repeated sampling on the same individuals is rarely done. There is thus an inherent assumption that different colonies within the same population behave similarly in their gametogenic developmental pattern. Our recent studies on reproductive development in tagged branching black and hard coral colonies revealed differences in the pattern of gametogenesis both at the individual colony, as well as the modular levels within the same colony. This led us to re-examine past and recent data on gametogenesis in both hard and soft corals. In particular, asynchronous development, uneven presence of gametes, split spawning both in temporal and spatial scales may all suggest the presence of individual colony or modular based differences in the reproductive patterns in these corals.

12A Life histories & reproduction
Friday 13 July, 1115, Sebel Bluewater

Environmental variables associated with coral spawning synchrony

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Determining the proximate cues driving coral spawning synchrony is one of the major goals of coral reproductive ecology. Here, we test for correlations between the month of spawning in *Acropora* assemblages and various environmental parameters, including sea surface temperature (SST) and photosynthetically active radiation (PAR) at 46 locations in the Indo-Pacific. Preliminary analyses suggest a strong correlation between PAR, SST and the month of spawning, with spawning at many locations occurring when PAR and rates of change in SST are highest. We hypothesise that PAR and SST are the most reliable proximate cues by which to synchronise spawning over the broad geographical scale of most coral populations.

12A Life histories & reproduction
Thursday 12 July, 0930, Sebel Bluewater

Synchronous spawning of scleractinian corals in the Red Sea

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Multi-specific synchronous spawning is a reproductive strategy used by scleractinian corals that has now been described from coral reefs in 23 locations globally. While high multi-specific synchrony in the reproductive condition of *Acropora* colonies has been documented in the Red Sea in April and/or May, multi-specific synchronous spawning has not been directly observed. In April 2011, we found mature oocytes in 81% of 92 colonies from 10 *Acropora* species as well as in some faviids on reefs near Thuwal, Saudi Arabia (22°18'N, 38°57'E). On the night of 16th April 2011, two nights before the full moon, we first observed egg-sperm bundles in *Acropora* polyps at 20:30 h. Between 22:30 h and 23:45 h, 43 colonies from 10 out of 13 surveyed *Acropora* species released egg/sperm bundles, including 3 species that had not been observed to spawn previously (*A. plantaginea*, *A. parapharaonis*, and *A. lamarcki*). This is the first documented multi-specific synchronous spawning event in the Red Sea. Our observations demonstrate that the asynchronous spawning pattern at Eilat in the Gulf of Aqaba is not representative of the Red Sea and provide further support for the prediction that these events are characteristic of all speciose coral assemblages. Nonetheless, spawning was not restricted to April with more acroporids and faviids containing mature gametes in May and June. Within these months we observed spawning in a further 9 species including *P. verrucosa* which spawned during the day.

12A Life histories & reproduction
Thursday 12 July, 1630, Sebel Bluewater

Environmental controls of fecundity of three Indo-Pacific coral species

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Among life functions of coral, reproduction appears to have the narrowest tolerance to stress, while being critical for maintenance of populations and evolution. However, relatively little is known about the effects of environmental stressors on reproductive output, especially in equatorial climes where corals exist close to their thermal tolerance limits. Gametogenic cycles and reproductive output were investigated in three common broadcasting scleractinian corals *Hydnophora exesa*, *Merulina ampliata* and *Echinopora lamellosa* at three fringing reefs, south of Singapore. All three species showed strong seasonality and broadly similar patterns of gametogenesis, with bi-annual peaks in fecundity occurring primarily in April, followed by a smaller secondary peak in October, although not all species necessarily complete this second gametogenic cycle. Both periods coincide with the inter-monsoon, during which tidal flushing is poorest. Reproductive fecundity in all three species significantly declined from 2009 to 2011, although spatial effects in these were prominent. Results indicated that oogenesis occurred over three to four months, during which fecundity metrics showed strong links with water temperature, total organic carbon, organic phosphorus and nitrogen, faecal coliforms, enterococci and total petroleum hydrocarbons. The effects of a bleaching event in mid-2010 had large effects on reproductive output, with reproductive failure in all three species in October 2010. This suggests these corals are sensitive and susceptible to deteriorating water quality within relatively short time frames. Consequently, variations in fecundity are highly relevant indicators of sub-lethal stress and monitoring coral reproductive output is critical to successful coral reef management.

12A Life histories & reproduction
Thursday 12 July, 1545, Sebel Bluewater

Reproductive benefits of no-take reserves vary latitudinally for *Plectropomus leopardus*

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No-take marine reserves (NTRs) are expected to benefit fisheries via recruitment subsidy to fished areas. Quantifying the contribution of NTRs to egg production is the first step in evaluating the potential for recruitment subsidy. We quantified annual fecundity and egg production per unit area (EPUA) for the commercially important common coral trout, *Plectropomus leopardus*, between fished and NTR reefs in four Great Barrier Reef (GBR) regions. Reproductive potential between NTRs and fished reefs varied significantly among latitudes. Fecundity was approximately 200% greater and EPUA 260% greater on NTRs than fished reefs in the central GBR. Annual fecundity and EPUA were significantly greater on fished reefs than NTRs in the northern GBR. It was difficult to detect differences between NTRs and fished reefs in the southern GBR because of small numbers of spawners available to measure fecundity, despite overall greater abundances in the south. *Plectropomus leopardus* densities were 2-5 times lower in the central GBR than the north or south but higher proportions of reproductively mature females

meant EPUA on central GBR NTRs was 1800-4500% greater than on NTR reefs in the two southern regions and 530% greater than reefs in the northern region. Male biased sex ratios, infrequent spawning, and low annual fecundity in the southern GBR limited the prospective reproductive benefits expected from significantly higher population densities. This study highlights the importance of considering spatial variation in EPUA when assessing prospective benefits of NTRs, particularly if recruitment subsidy is an objective of NTR implementation.

12A Life histories & reproduction
Friday 13 July, 1430, Sebel Bluewater

What is a weedy coral? Identifying life-history strategies of reef-building corals

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There is increasing concern that human impacts are causing a shift from historically dominant reef-building corals to assemblages of stress-tolerant and 'weedy' opportunistic species. However, there is currently no framework to classify Scleractinian corals into life-history strategies that would allow for testing of these predictions. We collected species-level trait information for all known species of Atlantic and Indo-Pacific reef-building corals from taxonomic monographs, identification guides and published literature. Our final database contained 11 characteristics related to colony growth form and size, reproduction, growth rates, predation, and zooxanthellae (*Symbiodinium*) diversity. Using hierarchical clustering and random forest analyses, we identified three life-history strategies consistent across Atlantic and Indo-Pacific taxa: 1) competitive species with a branching and plating growth form that grow quickly, reach large colony sizes and reproduce by broadcast spawning; 2) stress-tolerant massive species that grow slowly and reproduce by broadcast spawning, and 3) weedy species with small branching or submassive colonies and brooding reproduction. Interestingly, these groups bear a strong resemblance to primary life-history strategies in plants. We also compared the IUCN Red List assessments of species within each life-history strategy and found that competitive species have the highest risk of extinction followed by stress-tolerant and weedy species. The life-history strategies we have identified in reef-building corals identify 'winners' and 'losers' based on life-history traits and can allow us to predict shifts in coral assemblages on future reefs.

12A Life histories & reproduction
Friday 13 July, 1030, Sebel Bluewater

Coral dynamics in space and time: modeling coral populations in Hawaii

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Corals have complex life-histories including sexual and asexual reproduction, fission and fusion of colonies, and a lack of discrete stage structure that makes demographic modeling a particular challenge. Previous studies have used matrix models for coral population dynamics; however, this approach is limited by arbitrary imposition of size classes and parameter estimation requirements that increase multiplicatively with the number of size classes. In contrast, integral projection models (IPMs) use biologically meaningful, continuous functions for growth, survivorship, and fecundity as a function of size, which can be fit from data using mixed-model approaches in a likelihood framework. Here, we compare population projections for coral populations across six sites around Maui (Hawaii, USA). At each site, individual coral colonies were tracked in five permanent photoquadats over six years. We jointly fit individual growth, mortality, and recruitment at all sites, with site and depth and their interaction as fixed effects, and plot and year as a random effects. We explore site-specific differences in mortality and growth rate across years, compare growth rates between shallow and deep sites, and compare the relative magnitude in spatial and temporal variation in growth rate. We discuss how spatial patterns of variation relate to local site characteristics and management regime.

12A Life histories & reproduction
Thursday 12 July, 1500, Sebel Bluewater

Aspects of the early life history of *Montipora capitata* in Hawai`i

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Montipora capitata is a broadcast spawning hermaphroditic coral. It spawns from late spring to early fall. Three aspects of its life history were investigated in Kaneohe Bay, Hawaii - the survivorship and growth of newly settled individuals and 'visible' recruitment. To follow recently settled larvae in the field, plates at study sites were either seeded with larvae ('seeded plates'), or natural settlement occurred to plates ('field plates'). *Montipora capitata* cumulatively made up approximately

90% of recruits to the field plates. Spikes of *M. capitata* settlement occurred after spawning events in summer with lower settlement after spawning events in fall and spring. Survival of recruits was low. Of the initial recruits on the seeded plates, 0.03% survived for 21 months. *Montipora* growth, measured as rate of polyp increase, was also low with a high proportion of recruits remaining as a single polyp for an extended period. The growth and survival of *M. capitata* recruits were significantly lower than a gonochoric broadcast spawning species, *Porites compressa*, and a brooding species, *Pocillopora damicornis*, which both also settled on the field plates. Visible recruitment had previously been measured on concrete blocks immersed for up to 39 months. *Montipora* juveniles made up less than 1% of all visible recruits after 39 months. *M. capitata* is potentially a long-lived species. Even the low levels of recruitment observed in these experiments could maintain genetic diversity within populations and provide for recolonization of reefs after major disturbances.

12A Life histories & reproduction
Thursday 12 July, 1230, Sebel Bluewater

Do corals with maternal (vertical) symbiont transmission acquire symbionts?

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The larvae (planulae) of many coral species do not contain the obligatory symbiotic algae, *Symbiodinium*. These planulae acquire symbionts from the environment (horizontal transmission), potentially establishing a host/symbiont genotypic combination that is the most suited for that environment. Conversely, planulae of some coral species receive symbionts from the maternal colony (vertical transmission). It is unknown whether these planulae can acquire symbionts from the environment. Using denaturing gradient gel electrophoresis (DGGE), we confirmed previous reports that in the Gulf of Eilat, Red Sea, shallow water (<5 m) *Stylophora pistillata* coral colonies host clade A *Symbiodinium* while deep water (>24 m) colonies host clade C. *S. pistillata* broods its planulae and releases them with a complement of *Symbiodinium*. The objectives of this study were to determine, using DGGE and real-time PCR, the symbiont identity in shallow and deep water adult corals and their respective planulae. Adult *S. pistillata* colonies displayed a dominant symbiont type according to depth, ITS2 type A1 in shallow, and C72 in deep. Real-time PCR uncovered that the adults also contained low levels of the other symbiont clade. The planulae, on the other hand, only contained the dominant symbiont of their maternal colony. Juveniles in shallow and deep water predominantly hosted the dominant symbiont found at that depth, although exceptions occurred. Only the deep water juveniles, however, had background levels of clade A symbionts. Determining the potential flexibility of this symbiosis at all life stages is essential to understanding the adults' symbiosis, gene flow, and population structure.

12A Life histories & reproduction
Friday 13 July, 1000, Sebel Bluewater

The larval fish pelagic phase: a sanctuary from harmful parasites?

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The role of parasites in settlement processes of coral reef organisms is relatively unexplored. We evaluated potential fitness consequences of pelagic and reef-based parasites (gnathiid isopods) on fish. Larvae captured in light-traps were infected mostly with worms (cestodes, digeneans, monogeneans, nematodes, and turbellarians). Some Apogonidae (*Apogon trimaculatus*) and Serranidae (*Plectropomus* sp.) had hundreds and thousands of cestodes per fish, respectively. *Plectropomus* sp. and Pseudochromidae had 59±6 (mean±s.e) and 26±6 hemiurid digeneans per fish, respectively. Other families (Blenniidae, Chaetodontidae, Lutjanidae, Mullidae, Nemipteridae, Pomacentridae, Siganidae, and Sphyraenidae) had 0 to 1 median parasites per larva. Variation in parasite load among larval fish species suggests possible differences in larval histories. Critical swimming speed and parasite load were not significantly associated for *Apogon taeniophorus*, *A. trimaculatus*, *Lethrinus* spp., and *Plectropomus* sp. larvae. Thus, parasites obtained in the larval period did not affect fish swimming performance, a potentially important indicator of fish settlement success. In contrast, fish mortality was associated with gnathiid isopods; mortality associated with exposure to gnathiid attack tended to decrease with increasing size of larval fish species. There was also an interaction between gnathiid exposure and parental care on fish mortality for *Acanthochromis polyacanthus* (Pomacentridae) juveniles, a species without a pelagic phase; mortality was higher for fish without parental care. We conclude that the pelagic larval phase may allow fish to escape attack from reef parasites when fish are small and most

vulnerable. As a corollary, protection from parasites may be a critical component of the parental care given by *A. polyacanthus*.

12A Life histories & reproduction
Friday 13 July, 1400, Sebel Bluewater

Asynchronous and multispecific spawning patterns among Maldivian equatorial reef corals

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Coral spawning patterns in equatorial reef regions have been less extensively studied compared with many tropical reef regions. This study provides the first detailed records of coral spawning patterns on equatorial reefs in the Maldives Archipelago (4°N), central Indian Ocean. Coral reproduction was studied between March and May 2007 and 2008 at Vabbinfaru and Angsana reefs, Male Atoll. Direct observations of coral spawning during extensive night dives after the full moon periods in early April 2007 and March 2008, together with repeated sampling of ~200 tagged gravid coral colonies provided detailed data on reproductive patterns at the study sites. More than 20 coral species including Acroporidae, faviids, *Hydnophora* and *Porites* were recorded to release gametes during the study. Spawning tended to be asynchronous within and among species, with partial spawning of individual colonies within some populations occurring over many nights during multiple lunar phases. Some pulsed multispecific coral spawning was observed after full moon periods, but asynchronous gamete release continued to occur in the remaining gravid tagged corals over subsequent weeks. Some soft corals, holothurians and molluscs were also observed to spawn during the study periods, but relatively few individuals spawned together. The protracted and relatively asynchronous coral spawning patterns with occasional pulsed multispecific spawning events observed in the Maldives contrast markedly with highly synchronous mass spawning events documented in some tropical reef regions. These data support the results of some previous studies that have recorded protracted breeding periods and less synchronous reproduction among reef corals on other equatorial reefs.

12A Life histories & reproduction
Thursday 12 July, 1000, Sebel Bluewater

Coral reproduction in Moorea reefs: timing, reproductive output and survivorship

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Coral reproduction is a key process for the persistence and renewal of corals. Various studies have assessed how and when corals released gametes in several tropical areas. While this body of work serves as an important baseline for better understanding coral reproductive biology, such information is unfortunately lacking for many regions. This is particularly true for French Polynesia, where only one study was published on coral spawning. Against this backdrop, the current project has addressed this knowledge gap by identifying the narrow time frame during which the major coral species (from different genera, e.g. *Acropora*, *Montipora*, *Montastrea*, *Fungia*) of Moorea lagoon spawned. Interestingly, while coral spawning was though to be concentrated between September and November in French Polynesia waters, our study indicated that corals also spawned from February to April for *Fungia*, *Montipora* and *Montastrea* species. Knowing when coral spawning occurs is the first glance to further works on coral reproduction. As such, our study has also assessed whether the reproductive output differ among the various species investigated and how early life stages of corals deal with environmental stressors. Results clearly showed that reproductive output (e.g. bundle size, egg number per bundle) and resistance to stress differed among coral species. Further analyses are currently exploring whether the life stages of corals do matter when facing stressors. This project provides new insights into the effects of stress on coral reproductive life cycle, information that has the potential to enhance the conservation of coral diversity from French Polynesia.

12A Life histories & reproduction
Thursday 12 July, 1715, Sebel Bluewater

A physiology-based life-history classification system for reef corals

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Functional classifications of life-history strategies can provide information about the processes at play within a community based on a snap-shot of present community structure. In coral reef science it is becoming increasingly

important to predict how the productivity and resilience of coral communities will change under different climate scenarios. To predict coral community responses to climate change requires knowledge of the productivity of different species within coral assemblages, and the sensitivity of different functional groups to environmental change. However, classification of coral life-histories is largely based on broad differences in coral growth form, rather than on an understanding of the physiological traits that influence reef productivity and growth (such as photosynthesis, respiration and calcification). In this study we review several decades of literature on patterns of energy acquisition and allocation among scleractinian corals to determine, qualitatively, how different colony morphologies correspond with different physiological strategies. Using a simple model we demonstrate that, averaged across the available data for different species, mound-shaped corals have to live approximately twice as long as branching corals in order to have the same reproductive output. This study demonstrates how patterns of energy allocation underlie differences in the life-history strategies of coral species.

12A Life histories & reproduction
Thursday 12 July, 1515, Sebel Bluewater

Coral recruitment at Gorgona Island, Tropical Eastern Pacific

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Coral recruitment is a key process in the maintenance and recovery of coral reefs. This process has been poorly studied in the Tropical Eastern Pacific, where coral reefs have degraded as they have elsewhere around the world. At Gorgona Island, in the Colombian Pacific, there has been a notable reduction in coral cover in shallow areas during the last decade. However, little is known about coral recruitment and the potential for coral reef recovery after perturbations. To estimate rates of coral recruitment on natural substrates we established 10 permanent 10 x 2 m plots in each of 2 reefs and examined them *ca.* one month and a half in search of new juveniles. The density of juveniles recorded in Gorgona was very low, being 0.09 ± 0.27 ind/m^2 (X ± SD) for each reef. Playa Blanca reef presented a greater recruitment rate (0.017 ind/m^2/month) than the rate obtained in La Azufrada (0.001 ind/m^2/month). The reason of this difference is that between February and April the recruitment rate of Playa Blanca was twice the rate found in La Azufrada, 0.038 ind/m^2/month. Considering that in the Mexican Pacific (area that has recorded the highest density of juvenile coral so far) this rate varied between 0.07 and 1.7 ind/m^2/month, the results found in this study suggest that Gorgona's coral reefs have a low monthly recruitment rate, probably the lowest reported so far in Tropical Eastern Pacific coral reefs.

12A Life histories & reproduction
Thursday 12 July, 1130, Sebel Bluewater

The solitary coral *Fungia fungites* is a gonochoric brooder

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The solitary coral *Fungia fungites* is abundant in shallow patch reefs at Okinawa, Japan in 1-5 m depth. We studied the sexual reproduction of this species using dissection, histology and laboratory observations of gamete release. In contrast to almost all other species in the family Fungiidae, we report *F. fungites* to be a gonochoric brooder. Oocytes were visible histologically from November to September and testes began developing three months later and continued throughout the reproductive period. Mature gametes appeared in April, and were continually produced until September. In aquaria, male individuals released sperm simultaneously, on consecutive lunar cycles (July-September), in the early morning following a full moon. Planulae were shed during the night of the full moon for 5 consecutive nights (July- August). Brooded planulae larvae, of different developmental stages were observed in every month throughout May to September. Male to female ratio was 2:1 in the mid-reproductive period, with mean diameters of the smallest males and females reaching 2.7cm and 2.9cm, respectively. The skewed sex ratio appears to compensate for possible male sperm limitation. While not all males ejected sperm during the whole reproductive period, all females always contained mature eggs and planulae of various developmental stages. It is possible, therefore, that due to sperm limitation, males must use their reproductive resources during shorter periods of time than females. The production of planulae of different developmental stages may enable *F. fungites* to substantially increase its dispersal distances.

12A Life histories & reproduction
Thursday 12 July, 0945, Sebel Bluewater

Population dynamics of a tropical coral in Sydney Harbour

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Plesiastrea versipora is widely distributed within the Indo-Pacific and is one of the few scleractinian corals to extend beyond 25°N and 25°S. This study focuses on a rare instance in which significant numbers of *P. versipora* are found at a location in Sydney Harbour, Australia. Here we empirically quantify demographic rates (growth, survival and fecundity) and parametrise a population model to build an understanding of biogeographical limits to population viability and the most sensitive life history stages to environmental change. Colonies were monitored monthly for one year using digital photography to measure growth, shrinkage, and mortality. Life history traits (e.g. sexuality, fecundity and reproductive mode) were determined by dissections and histological analysis of coral fragments collected monthly for one year. *Plesiastrea versipora* in Sydney Harbour is gonochoric supporting recent phylogenies that suggest the species be removed from the family Faviidae, the members of which are otherwise all hermaphrodites. The disappearance of gametes from all colonies between samples in February and March 2010 suggests *P. versipora* is a broadcast spawner, spawning sometime around the full moon in February. We are now parameterising a Leslie transition matrix model to calculate population-level metrics such as intrinsic population growth rate and lifetime reproductive output. Comparisons with existing data from locations on the Great Barrier Reef will shed light on the traits and demographic rates required for tropical corals to expand to temperate habitats.

12A Life histories & reproduction
Thursday 12 July, 1700, Sebel Bluewater

Pathways of hermaphroditism of three species of groupers in Brazil

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Most groupers present sexual development as monandric protogynous hermaphrodite, where males develop from mature females. Some species of epinephelids have also showed a pattern of diandric protogynous hermaphroditism in which males can been originated from immature females (primary males) or from mature females (secondary males). We have studied the reproductive biology of three species of small groupers that are commonly captured in shallow reef areas in Brazil and found two pathways of hermaphroditism. The coney *Cephalopholis fulva* and the rock hind *Epinephelus adscensionis* are monandric protogynous hermaphrodites while the mutton hamlet *Alphestes afer* is a diandric protogynous hermaphrodite. Spawning occurred between the end of winter (July-August) and beginning of spring (September-October) for all studied species. The size of first maturation for females of *A. afer* and *C. fulva* was L_{50}=18 cm TL and for E. adscensionis was L_{50}=20 cm TL. Transitional individuals of *A. afer* measured between 18-21.7 cm TL; of *C. fulva* 20-27.1 cm TL; and of *E. adscensionis* between 26-33 cm TL. Only *A. afer* presented one immature female (16 cm TL) with spermatic cripts, indicating that the smaller males of the population were primary males. Fish mortality often has an effect on the distribution of sizes and sexes in populations, especially sequential hermaphrodites. Reference points are important indicators for management, as well as to understand the pathways of hermaphroditism as those populations have been increasingly exploited by fishing in Brazil.

12A Life histories & reproduction
Friday 13 July, 1245, Sebel Bluewater

Exploring *Acropora* sperm proteins that contribute to species-specific fertilization

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The fertilization step is predicted to be crucial for the reproductive isolation in the genus *Acropora*. Although most *Acropora* species spawn synchronously, fertilization occurs species-specific manner in the mixture of gametes from many species. How do sperm recognize and select eggs from own species? It would be expected that several proteins with species-specific amino acid sequences are present at sperm surface and those proteins may be involved in the species-specific fertilization. To explore the polymorphic sperm proteins in the *Acropora*, I conducted following experiments using *Acropora digitifera* as a main species; 1) making antibodies against sperm proteins with species-specific epitopes in *A. digitifera*; 2) isolation of cDNA clones that encode species-specific epitopes in many species; 3) analysis of molecular sequence evolution of those genes in terms of non-synonmous/synosymous substitution rate (dN/dS:Ï‰); 4) involvement of those sperm proteins on species-specific fertilization. From above investigation, following results are suggested; a) *Acropora* sperm conserve polymorphic-proteins, most of which were localized at head region; b) rates of molecular evolution of some genes are rapid; c) those proteins are slightly involved in species-specific

fertilization. In crossing experiments, sperm of *A. digitifera* were treated with the antibody prior to mixture with eggs from the non-crossing species *A. intermedia*. Although the treatment did not induce high rate of hybridization, genotyping of those embryos with PCR suggests that several fertilized-embryos were hybrid between *A. digitifera* and *A. intermedia*.

12A Life histories & reproduction
Thursday 12 July, 1215, Sebel Bluewater

Conflict resolution in territorial reef fishes: interactions between body size and behaviour

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Many fishes and other organisms inhabiting coral reefs are highly territorial, defending smaller or larger patches of reef either seasonally or year round. The function of territoriality is to defend essential resources, such as breeding sites or food sources, against inter- or intraspecific competitors. Body size is an important factor in deciding the outcome of these interactions; larger individuals generally hold prime resources and experience less aggression from smaller individuals. However, in long-lived species with indeterminate growth, there will be considerable body size variation among individuals. Resource conflicts among animals are typically resolved by either signalling or physical fights. Using the sapphire damsel *Chrysiptera cyanea* as a model organism, we analysed how the relative size of two male competitors affected the way conflicts were resolved, and the outcome of the conflict. As expected, we found that larger males invariably won conflicts, as evidenced by monopolisation of a breeding resource in the presence of females. However, conflict resolution typically involved a prolonged phase of non-violent visual displays even when size-asymmetries were pronounced. The results highlight the importance of behavioural displays in territorial spacing in reef fishes.

12A Life histories & reproduction
Friday 13 July, 1200, Sebel Bluewater

Scleractinian corals seed sediments with free-living symbionts for future recruits

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Most scleractinian coral species broadcast spawn gametes that develop into aposymbiotic larvae. Settled corals must acquire *Symbiodinium* from a free-living (FL) reservoir. Little is known about the source and spatial variability of this reservoir, but corals may be important contributors due to their regular expulsion of *Symbiodinium*. This possibility was investigated at Heron Island, Great Barrier Reef, Australia. Before spawning, colonies of *Acropora millepora* and *A. aspera* were collected and housed in aquaria. Gametes of each species were collected at spawning time and reared. Pre-conditioned terracotta tiles were then made available as settlement substrate. Following spawning, branches of approximately 10 cm in length of each species were collected from the reef and transferred to individual wells containing 20 ml of autoclaved reef sediment in a closed, filtered seawater system. Immediately following settlement in sediment free aquaria, newly-settled corals were moved to treatment chambers containing: sediments exposed to adult branches, autoclaved sediments (control) or just seawater (control) and maintained for two weeks. Viable *Symbiodinium* cells were detected with light microscopy in all coral branch treated sediment replicates, demonstrating that corals can seed reef sediments with symbionts during short time frames. Both species of newly-settled corals exposed to coral-treated sediments acquired symbionts, but there was no acquisition in the control chambers containing only autoclaved sediment, or just seawater. This demonstrates that corals contribute to the establishment of a FL reservoir of symbionts available for acquisition.

12A Life histories & reproduction
Friday 13 July, 1415, Sebel Bluewater

Coloration signals dominance in a coral reef fish

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Reef fishes are famous for their often extravagant coloration. Surprisingly, however, the reasons behind reef fish splendour are not well understood. In particular, there has been little focus on the roles of coloration in mate attraction and status signalling, processes that have proven central in explaining splendid colours and other ornaments in a wide range of terrestrial and freshwater organisms. We quantified orange tail coloration of a small damselfish, the sapphire devil *Chrysiptera cyanea*, and tested if more colourful individuals were dominant in male-male interactions. We

matched pairs of males of similar size, but with markedly different degrees of tail coloration, and observed visual display interactions and aggressive encounters. Dominance tests were made both in the absence and in the presence of a female potential mate. In both tests, male tail coloration was positively associated with dominance, and dominance was linked to the ability to monopolize an artificial nest for breeding. Competition for breeding sites and territories is extreme on the reef. We suggest that one important function of extravagant reef fish coloration is to signal competitive abilities, and thus resolve intraspecific resource conflicts on the reef.

12A Life histories & reproduction
Friday 13 July, 1230, Sebel Bluewater

Quantifying connectivity between mangroves and reefs by otolith microchemistry

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Mangrove forests are one of the world's most threatened tropical ecosystems and are strongly connected to coral reefs as many reef fish species use mangroves as nursery habitats. The degree to which these species can survive the disappearance of mangroves depends on whether mangroves are obligatory, essential or accessory juvenile habitats. In this study, we used otolith microchemistry to assess the role of mangroves as nursery habitats for the blackspot snapper (*Lutjanus fulviflamma*) in New-Caledonia. Fish were collected in mangrove and reefs at 11 sites around the island. LA-ICP-MS analyses of otolith edge were used to determine multi-element signatures that discriminate reefs and mangroves. These signatures were then used to determine whether adults collected on the reefs had spent their juvenile life in mangroves. We found that over half of adults displayed a mangrove signature in the juvenile part of their otolith. This highlights the importance of mangroves for the life cycle of the blackspot snapper but suggests that mangroves are essential, not obligatory nursery habitats for this species.

12A Life histories & reproduction
Friday 13 July, 1130, Sebel Bluewater

Regular spawning and larva production in a laboratory *Aiptasia* population

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The mutualism between reef-building corals and their intracellular dinoflagellate algae (genus *Symbiodinium*) is of great ecological, economic, and aesthetic importance but remains poorly understood at the molecular and cellular levels. The small sea anemone *Aiptasia* is also symbiotic with *Symbiodinium* spp. and is emerging as an important model system for study of the molecular and cellular biology of cnidarian-dinoflagellate symbioses. It has long been apparent that the ability to induce sexual reproduction in the laboratory would be of great value: regular availability of larvae would allow important studies that would otherwise be difficult or impossible (given the seasonal spawning of most cnidarians in the field), and recapitulation of the complete life cycle in the laboratory would open the door to genetic analysis, which has been of enormous power in other model systems. To this end, we have developed a protocol involving a cyclical light and feeding regimen that results in regular induction of spawning by both male and female individuals. Mixing sperm and eggs results in fertilization and the development of aposymbiotic planula larvae that remain alive for weeks and can take up compatible *Symbiodinium* strains, allowing studies of the mechanisms governing specificity of such uptake at the life-cycle stage at which it normally occurs in nature. We are currently attempting to determine which feature(s) of the cyclical regimen are critical for the induction of spawning as well as to identify conditions under which the larvae produced will settle and metamorphose into polyps.

12A Life histories & reproduction
Friday 13 July, 1015, Sebel Bluewater

Phase-shifts, recruitment failure and coral bleaching in the Gulf of Thailand

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Recruitment plays a vital rule in population dynamics and replenishment of scleractinian assemblages. We investigated variation in reproductive output and early recruitment of corals around the Talu islands in the central-south Gulf of Thailand in 2003, 2004 and 2010. Before 2010, coral assemblages around the Talu islands were dominated by massive *Porites* intermixed with high abundance of *Acropora florida*, *A. hyacinthus* and *A.*

subulata. These reefs were only lightly affected by bleaching in 1997-98, when reefs in neighboring Chumphon province were badly damaged. More than 70% of coral colonies across all species of *Acropora* contained mature oocytes during the February-April spawning season in each years we sampled. However, *Acropora* recruits were consistently rare on settlement panels. Moreover, *Acropora* juveniles on natural substrates were also uncommon. This low level of replenishment appeared to have no effect on the vitality of *Acropora* population prior to 2010. In 2010, however, Talu's reefs experienced severe bleaching that killed 80% of all *Acropora* colonies, reducing total coral cover by approximately 60%. The reefs today are mostly populated by *Porites* bommies, and no *Acropora* juveniles have been observed either on settlement tiles or reef substrate since 2010. The 2010 die-off represents a rapid transition from high-cover, *Acropora*-dominated reefs to low-cover *Porites*-dominated assemblages that are unlikely to recover their previous community type for many decades. We hypothesize that many reefs in the Gulf of Thailand and South East Asia are also converging on a transition threshold, and may fail to recover from future pulses of coral mortality.

12A Life histories & reproduction
P240

Demography of long-lived octocorals: survival and local extintion

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Gorgonian corals are slow growing, long lived species, which highly branched, three dimensional colonies, form dense canopies on circalittoral reefs. As they are habitat forming and structuring species, the survival of the whole community depends in part, on their survival. Several gorgonian populations have been and are still affected by human disturbance which deeply affected their size and age structures. The Mediterranean red coral *Corallium rubrum* is a precious gorgonian which, heavily harvested populations, have changed their size and age structures. In general gorgonians show low recruitment and low dynamics, but when they are subjected to an increased mortality their population dynamics dramatically change. In 1999 and 2003 two anomalous mortality events, putatively linked to GCC, affected a population of the red gorgonian *Paramuricea clavata* at the Western edge of the Gulf of La Spezia (NE Ligurian Sea Italy). The availability of pre- and post-mortality demographic data allowed us to follow the trends of this population before and after the anomalous mortality over 12 years. In the first years after the mortality events, population density fell down and 90% of colonies died or suffered a partial mortality; moreover recruitment reduced by ½ and the dominant size classes shifted towards a smaller size. In the subsequent years population density increased, showing positive growth rates, damaged colonies recovered and the recruitment doubled the 1998 values. We will present our findings about the basic life history features and the modelled dynamics of this population.

12A Life histories & reproduction
Thursday 12 July, 1745, Sebel Bluewater

The impact of climate change on the reproductive success of different coral species

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Ocean acidification and increased seawater temperatures will impact our coral reefs in the near future. The effects are expected to be most profound at the sea surface, where fertilization of most broadcast-spawning reef coral species takes place. Knowledge about the response of coral reproductive traits to climate change is essential to understand the dynamics of reef coral communities under the future hostile environment. The response to climate change is expected to differ between coral species and between latitudinal locations. Corals from high-latitude reefs could be more severely affected by acidification, since carbon dioxide dissolves more easily in colder water. Additionally, local adaptation to seasonal differences in seawater temperature may also influence their thermal tolerance. To determine the effect of climate change on coral reproduction, we studied the fertilization success of different broadcast-spawning reef coral species (mainly Acroporidae and Faviidae) under ambient conditions (27°C and ~500 ppm CO_2) and under conditions predicted for 2100 (IPCC 2007, worst case scenario; 1000 ppm CO_2 and 31°C) using a 2x2 factorial design. Seawater pCO_2 was manipulated experimentally using a pH/CO_2 control system. Experiments were repeated at three different latitudinal locations in the Kuroshio Region (Green Island (Taiwan), Okinawa (Japan) and Kochi (Japan)). Data of 7 different coral species are being analyzed and will be reported at the ICRS in 2012.

12A Life histories & reproduction
Thursday 12 July, 1530, Sebel Bluewater

Early gametogenesis in scleractinian coral, *Euphyllia ancora*

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To date, histological analysis of the gametogenesis has been reported in many coral species. However, the development of early stage of germ cells, such as germ-line stem cells, has not been examined extensively. To better understand coral gametogenesis, we conducted immunohistochemical analysis for the early stage of germ cells by tracing the expression of Vasa, a germ-cell marker gene, in gonochoric species *Euphyllia ancora*. For the first time in a coral species, the full length of *Euphyllia ancora* vasa (Eavas) cDNA was cloned and polyclonal antibody against Eavas was produced. Immunohistochemical analysis in the male colony revealed that the immunoreactive Eavas (irEavas) cells localized on mesenteries along the mesoglea between the mesenterial filaments and the retractor muscle bands without forming cell cyst during 1~5 months after spawning. The sizes of irEavas cells were approximately 5 µm with large nucleus and relatively small cytoplasm in males. The formation of spermatogonial cyst occurred 6~7 months after spawning. The irEavas signals were detected on male germ cells until early stage of spermatocytes. In females, irEavas signals were detected on oogonia and early-stage oocytes that existed in mesenteries along the mesoglea 1 month after spawning. The cell sizes of oogonia were approximately 5 µm. The irEavas signals were detected on growing oocytes until 5 months after spawning. These results suggested that Eavas would be a useful germ-cell marker to investigate the characteristics of the early stage of gametogenesis in the coral. The present data would be valuable for understanding the developmental process of coral germ cells.

12A Life histories & reproduction
Thursday 12 July, 1145, Sebel Bluewater

The molecular basis of sex in corals

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Stony corals (order Scleractinia) are the major architects of coral reefs and, although anatomically simple, these sessile organisms exhibit a wide variety of reproductive ecologies/strategies at both the individual and population levels. Despite being one of the most intensively studied aspects of coral biology over the past thirty years, the molecular mechanisms underlying these various reproductive strategies are largely unknown. Here we present a preliminary analysis of the molecular bases of sexual differentiation, sex determination and maturation of sequentially hermaphroditic coral species based on high throughput DNA sequencing (Illumina) and reference to the published genomes of *Acropora* species. These experiments revealed that distinct set of genes are differentially expressed between the sexes, some of which have counterparts in higher animals but many of which are taxonomically restricted. The repertoire of genes involved in sexual differentiation in corals is surprisingly complex, some of these genes having roles in other aspects of coral biology. Our major aim is to understand how sexual differentiation in corals fits into the broader scheme of the evolution of such processes within the animal kingdom, where few general principles are clear.

12A Life histories & reproduction
Thursday 12 July, 1645, Sebel Bluewater

Impacts of sedimentation on coral settlement, Pelekane Bay, Hawaii

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While coral recruitment has been studied historically throughout regions, it is crucial to investigate its pattern and process as coral reefs decline at multiple scales. Settlement and recruitment may be strongly affected by habitat quality and associated sink-source dynamics. In Hawai`i, coral settlement and recruitment has been known to vary substantially in a given time and space. Such variations may be influenced by episodic, yet severe events, of terrestrial runoff and sediment re-suspension. Processes of sedimentation in Pelekane Bay, West Hawai`i, have been of great concern due to habitat and reef community degradation resulting in significant loss of ecological function and socio-economic value. Field investigation of coral settlement was conducted in Pelekane Bay and adjacent reefs over the summer of 2011 in order to identify any spatial patterns of coral settlement in relation to sediment regime and turbidity at a local scale. Settlement arrays were deployed at 41 sites at depths of 2, 5, and 15 m along a sedimentation gradient. The relationship among settlement, adult coral abundance, and habitats are being examined using environmental and benthic cover data collected from these sites. This study provides an important baseline for future

investigation of coral recruitment and community structure as related to an ongoing terrestrial restoration and runoff reduction project in the bay's watershed.

12A Life histories & reproduction
Thursday 12 July, 1115, Sebel Bluewater

Effects of parasites on young damselfish (*Pomacentrus amboinensis*)

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Early life history traits, such as larval growth, influence the success of fish in the transition from the larval to juvenile life phase. In contrast to knowledge of the prevalence of parasites in adult fishes and their negative impacts, few studies have examined the relationship between parasites and early life history traits of coral reef fishes. This study examined how parasite prevalence and load, as well as the relationship between parasite presence and growth, differed among life stages of the larvae and juveniles of the damselfish *Pomacentrus amboinensis*. Parasite prevalence (% infected) differed among life stages, with a significant decrease occurring between the larval stage immediately before settlement on the reef (97%) and recently-settled fish (60%); prevalence was also high for 4-month-old juveniles (90%), 7-month-old juveniles (100%) and adult fish (100%). Total numbers of parasites per fish decreased dramatically (4-fold) between larval and recently-settled fish, and then increased over time to levels similar to those observed in larvae, but did so more gradually than did prevalence. These patterns suggest that heavily infected recruits were preferentially removed from the population. Daily fish growth, from otolith increments, revealed that growth did not differ between parasitised and non-parasitised larval fish, whereas recently-settled fish that were parasitised had faster growth; parasitised recently-settled fish also displayed fast growth prior to settlement. These data provide evidence that parasites may explain some of the variation in growth observed among coral reef fishes after settlement, and thereby have a greater impact on population dynamics than previously understood.

12A Life histories & reproduction
Friday 13 July, 1145, Sebel Bluewater

Inhibitory effect of dopamine treatment on synchronous spawning in *Acropora tenuis*

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Most corals exhibit lunar-synchronized spawning rhythm. It remains unknown how they perceive cues from the moon and undergo gamete release around the specific lunar phase. In the present study, we examined effect of dopamine (DA) on the release of bundles in *Acropora tenuis*, which spawns around the full moon period. Colonies of *A. tenuis* (n = 4) were divided into small pieces and reared in 3 aquaria (20 L capacity) with running seawater under natural photoperiod and water temperature at Sesoko Station, Tropical Biosphere Research Center, University of the Ryukyus. At 1 month before predicted spawning lunar phase, they were continuously treated with DA (0.1 μM), DA (0.1 μM) + domperidone (an anti-dopaminergic drug; 0.1 nM) or without DA (control). Around the predicted spawning lunar phase, coral fragments without DA-treatment released many bundles while few bundles were released from the coral fragment with DA-treatment. Dopamine receptor cDNA was partially cloned from *A. tenuis*. It had 260 amino acid residues (926-bp) and showed phylogenetic identity to the family of D1. These results suggest that DA inhibits spontaneous release of matured bundles around the predicted spawning lunar phase though binding to DA receptor(s). It is known that DA acts as gonadotropin-release inhibiting factor (GnIF) in teleost fishes. Further researches would be needed to confirm whether DA functions as GnIF in coral reproductive mechanisms.

12A Life histories & reproduction
P112

Abundance patterns for juvenile versus adult corals on Australia's GBR

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A central goal in ecology is to determine the relative importance of processes that may influence the distribution and abundance of organisms. For organisms with complex life history such as corals, patterns of adult abundance are determined by the collective outcomes of processes acting upon each life-stage. Adult coral populations greatly depend

on the supply of pelagic larvae, their successful settlement and subsequent growth and mortality until reaching adult stage. These post-settlement processes are increasingly though to modify patterns established at the time of settlement and therefore shape population and community structure of adult corals. However, our understanding of the relationship between settlement rates, juvenile and adult corals abundance is limited. This study examined variation in the size, abundance and community structure of juvenile corals (<50 mm) across small and large-scale on the Great Barrier Reef (GBR), and compared these patterns to variation in abundance of adult corals. Patterns of abundance of juvenile and adult corals did not vary across the latitudinal gradient of the GRB, but there was marked variation at very local scale (within reefs). However, taxonomic composition of juvenile and adult assemblages showed strong spatial heterogeneity across small and large-scale. Overall, the abundance of juvenile corals was unrelated to the adult abundance of corals. This implies that there are significant levels of post-settlement mortality that mask stock-recruitment relationships on the GBR, or there is marked temporal variation in settlement and survival of juvenile corals.

12A Life histories & reproduction
Thursday 12 July, 1030, Sebel Bluewater

Telomere lengths of different developmental stages of a colonial coral

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If we can estimate coral's age using soft tissue, we will get a powerful tool to study population biology as well as life history of corals. At present we do not know whether colonies regenerated from fragments are of the same age as their original colonies and whether polyps comprising a colony are of the same age or not. The objective of this study was to measure the lengths of specific telomeres of a colonial coral, *Galaxea fascicularis* and to investigate whether the telomere length can be used as a measure of coral's age. We applied the single telomere length analysis (STELA) developed for human to the coral. We determined DNA sequences of some subtelomeric regions of *G. fascicularis* and designed 4 chromosome-specific primers for the STELA. We estimated the length of the double stranded region of a specific telomere based on the size of the STELA products. The telomere lengths of polyps isolated from 11 colonies varied in the range of 2-6 k bp, while that of sperm and planulae was around 3 k bp. Similar telomere length of sperm and planula larvae suggests the possibility of telomerase activity at early developmental stage. Further studies are necessary to investigate that the variable telomere lengths are due to telomere shortening in old polyps or polyps in old colonies. We successfully applied STELA to a colonial coral and opened the way to study the aging of colonial corals and possible rejuvenation during regeneration and asexual reproduction.

12A Life histories & reproduction
Thursday 12 July, 1730, Sebel Bluewater

Biological clock driven circadian transcription in *Acropora millepora*

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Circadian rhythms regulate many physiological, behavioral and reproductive processes. These rhythms are often controlled by light and daily cycles of solar illumination and entrain many clock regulated processes. In scleractinian corals, a number of different processes and behaviors are associated with specific periods of solar illumination or non-illumination (e.g., feeding and spawning). In order to explore if the genetic pathways that regulate many diurnal processes in other animals are conserved and active in stony corals we have undertaken an analysis of diurnal expression of a number of candidate circadian genes in the coral *Acropora millepora* using deep RNA sequencing (40 million reads) and quantitative PCR. Many examples of diurnal cycles of RNA abundance were identified, some of which are under the direct control of light cycles (e.g., cryptochrome 1 and timeless), and others that are under the control of an entrained biological clock and continue to cycle in a robust manner when kept in constant darkness (e.g., cycle, clock, cryptochrome 2 and eyes absent). Entrained cycles of circadian gene expression occur in both coral larvae that lack zooxanthellae and in adult tissue containing zooxanthellae. Corals therefore exhibit entrained circadian patterns of gene expression that may participate in the regulation of diurnal biological processes.

12A Life histories & reproduction
Thursday 12 July, 1200, Sebel Bluewater

Multi-agent cooperative negotiation for sex roles and reproductive shares in a group-forming hermaphroditic fish

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Theory on sex - and reproductive - allocation patterns in polygynous hermaphroditic animals has historically invoked purely competitive processes to derive evolutionary stable strategies. In contrast to this predominant view, I examine sex- and reproductive-allocation as collective-action problems. Specifically, using a simple game-theoretic model I show that both prospective losers and winners of a competitive hermaphroditic breeding game can increase expected lifetime fitness by adopting a cooperative negotiation strategy for sex- and reproductive-allocation. Cooperative negotiation maximises lifetime fitness by facilitating optimal sex allocation decisions and by enabling individuals to offset real-time reproductive losses against longer-term group benefits. I test the assumptions of the model using the group-forming hermaphroditic reef fish *Parapercis cylindrica*. Laboratory- and field-based experiments illustrate that individuals collectively settle on sex roles and reproductive shares prior to sexual differentiation and breeding attempts, and that individual and group fecundity are the outcomes of individuals' highly coordinated reproductive behaviour and physiology. Experimental data further illustrates that cooperative negotiation is made evolutionary stable via the establishment of reproductive, strategic, and communicative threat-points, whereby individuals return to more competitive behaviour in response to both breaches in negotiated settlements and unreliable information transfer. I highlight some potentially important interrelationships between collective sex - and reproductive - allocation, the dynamics of populations and communities, and the evolution of animal communication.

12A Life histories & reproduction
Friday 13 July, 1445, Sebel Bluewater

Coral embryos in a climate change hotspot

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Changing ocean temperatures and circulation patterns are altering larval dispersal and causing range shifts in many marine species. Rising sea surface temperatures and strengthening of the East Australia Current mean the southern edge of the Great Barrier Reef may become a stepping-stone for range expansion along the east coast of Australia. Coral larvae can survive in the plankton for many months and are likely to experience a range of temperatures as they disperse towards cooler latitudes. Here, we test the hypotheses that cooler water does not hinder dispersal as much as warmer water and that thermal tolerance varies among species. We used fertilization success, survivorship, and development rate as response variables to investigate thermal tolerance of *Goniastrea favulus* and *Acropora millepora* embryos. Embryos and larvae were exposed to temperatures -4°C to +4°C around ambient (24°C). Temperature had little effect on *G. favulus* fertilization while *A. millepora* fertilization peaked at ambient (96.7% ± 3.3) and was lower above and below this temperature. Embryos of both species took longer to reach gastrulation at lowered temperatures and development was faster in *G. favulus*, which has smaller eggs. Survivorship was lower at high temperatures, with larvae of *A. millepora* affected at +2ºC and +4ºC and *G. favulus* affected at +4ºC. Survivorship was not affected by temperatures below ambient in either species, suggesting cooler southern waters will not inhibit southward dispersal in eastern Australia. *G. favulus* embryos exhibited greater thermal tolerance than *A. millepora*, suggesting species will be differentially affected by climate change.

12A Life histories & reproduction
Thursday 12 July, 1015, Sebel Bluewater

The larval development of *Acropora robusta*

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Acropora robusta is a dominant species in Luhuitou Bay Sanya, China. Zygotes of *A. robusta* were collected in the field, and were cultured in the laboratory on the 27th April 2010. The coral planula larva began to settle 96 hours after spawning. When appropriate substratum was found, planula attached the substrate with their aboral side that inflated after attachment. At the beginning of settlement, *A. robusta* larva showed a bottle shape, afterwards shortened to pear-shape. Next, the larva emerged as persimmon-shape, and then typically had obvious septal mesenteries radiating from the central mouth region to bloom-shape. The calcification happened when 12 tentacles appeared. The larva of *A. robusta* had radially symmetrical proto-septa at first with lateral processes evident on the inner end of the 12 proto-septa. These processes developed into rods which grew perpendicular to the proto-septa, and fused with adjacent synapticulae to form the corallite wall. The synapticulae occurred near the mouth. Corallite grew up to colony in gemmation, with the endosymbiotic zooxanthella of *A. robusta* appearing 5 days after settlement.

12A Life histories & reproduction
Thursday 12 July, 1245, Sebel Bluewater

Theme 13. Fish & fisheries

13A Fish

Community assembly patterns in Atlantic reef fishes

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The processes influencing community assembly patterns on multiple scales are a central question in ecology and biogeography. Moreover, identifying such patterns is important to promote more efficient conservation of ecosystems and their biodiversity. We measured the variation in reef fish species composition across a ten-fold richness gradient from the perspective of taxonomic and functional groups, and body size categories. Data came from 36 reef fish checklists throughout the Atlantic Ocean. Species were assigned to functional groups in two levels: 1. broad trophic level and, 2. a refined combination of trophic level and feeding behavior. Body size categories were: small, medium-small, medium and large (<10, 10-25, 25-50, >50 cm). The proportion of species within those categories in relation to the total pool at each site was compared against a null model (bootstrapped 95% confidence limits, 1000 iterations). We found that the proportion of species within reef fish families and refined functional groups, are constrained within a range of values, despite a large range of local richness and latitude. On the other hand, for broad functional groups, the regional pool does not constrain the proportion of herbivores and carnivores in communities. In the case of body size, only the number of medium-small species in communities seems to be guided by the regional pool. Our results indicate that large-scale processes might influence the taxonomic composition of Atlantic reef fish communities. However, local filters could be operating on the functional and body-size composition of those communities.

13A Fish
Tuesday 10 July, 1230, Hall A

Learning temporal patterns of risk in a predator diverse environment

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Temporal patterns of predation risk have been shown to influence daily activity, reproduction, and territorial defence patterns in prey. However, the ability to respond to temporal patterns of risk in highly diverse predator communities such as coral reefs remains to be examined. Here, we investigated the ability of juvenile marine fish to learn to adjust the intensity of their antipredator response, to match the daily temporal patterns of risk they experience. Groups of lemon damselfish (*Pomacentrus moluccensis*) were exposed to one of two predictable temporal risk patterns for 6 days. 'Morning risk' treatment prey were exposed to the odour of predatory rockcod (*Cephalopholis cyanostigma*) paired with injured conspecific alarm cues in the morning, and rockcod odour only in the evening. 'Evening risk' treatment prey had the two stimuli presented to them in the opposite order. When tested individually for their response to rockcod odour alone, lemon damselfish from the morning risk treatment responded with a greater antipredator response in the morning than in the evening. In contrast, those lemon damselfish previously exposed to the evening risk treatment responded with a greater antipredator response when tested in the evening. The results of this experiment demonstrate that lemon damselfish have the ability to learn temporal patterns of risk and can adjust the magnitude of their antipredator response to match the threat posed by predators at a given time of day. Our results highlight the incredible sophistication of learned predator recognition by prey in a complex, multi-predator environment.

13A Fish
Tuesday 10 July, 1515, Hall A

Two decades of fish monitoring in a protected reef area

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Marine communities of the Pigeon Islets have been protected from spearfishing since the 80s, and protection has progressively increased to the current designation as a core area in the National Park of Guadeloupe. In parallel, the number of SCUBA divers has increased from about 1,000 divers per year in 1982, to 100,000 at the beginning of 2000. Monitoring of fish was conducted by *in situ* visual censuses along a permanent belt-transect (150 m long by 2 m wide), between 1998 and 2011. The fish community is affected by short- and medium-term cyclic fluctuations (nycthemeral, lunar and seasonal). The present communication will focus on the trends observed in the long-term evolution of the fish assemblage. Significant positive trends were observed for species

richness and fish biomass per unit area, with both increasing over the 23 year study period. Other ecological descriptors of the community, such as abundance of fishes per unit area, recruitment of juvenile fishes, and diversity indices (Shannon and Pielou) remained stable over this time period. With respect to feeding categories, the number and biomass of herbivorous and first order (C1) carnivorous fishes significantly increased over the period. For the big carnivorous residents (C2) decreases in the number of species and of their numerical abundance were observed. However, the biomass of this group increased.

13A Fish
Tuesday 10 July, 1700, Hall A

Molecular techniques show coastal ecosystems sustain fisheries on offshore reefs

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Many species of commercially important reef fish use mangroves and seagrass during juvenile stages before moving on to coral reefs as adults. This ontogenetic migration is an important consideration in the placement of protected areas, with the efficacy of reserve design for a particular species influenced by the spatial scales over which these habitats are connected. Here we investigate connectivity in yellowtail snapper (*Ocyurus chrysurus*), a commercially important reef fish that uses seagrass and mangrove areas for up to two years before recruiting on to coral reefs. Specifically we aim to identify which areas are the sources of adults which are fished by the small scale fishery on off shore banks. Using solution elemental analyses on the otoliths from juveniles, we define molecular signatures for fifteen sites on the north shore of Honduras separated by between 25 and 110 km, including from within six designated protected areas. We then use laser ablation coupled plasma mass spectrometry across the cross section of adult otoliths sourced from six fishing banks, to assign them to their nursery ground of origin by matching core signatures. Discriminant analysis accurately separated the different nursery grounds based on the concentrations of twelve elements in the dissolved otoliths, producing unique signatures for each area. The adult otolith results demonstrate how near shore areas are the principle source for the adults on the main off shore fishing banks, providing empirical evidence to support conservation of coastal wetlands due to the direct reliance of important fisheries on these areas.

13A Fish
Tuesday 10 July, 1130, Hall A

Prevention and repair of ultraviolet induced DNA damage in fish

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Ultraviolet (UV) radiation is a known carcinogen due to its high potential to damage the DNA of any organism exposed to sunlight. Protection is therefore vital for exposed organisms such as coral reef fish, and can be achieved by three basic mechanisms: via avoidance behaviour, via sunscreen compounds (MAAs) in external body mucus, and via internal repair of damaged DNA. This study focussed on the internal repair mechanism, specifically photorepair of DNA lesions known as cyclobutane pyrimidine dimers (CPDs). We exposed fish to experimentally manipulated light environments and quantified UV- induced DNA damage in conditions which allowed and prevented photorepair. Specimens (n=38) of the wrasse *Thalassoma lunare* were divided into experimental groups with high and low external protection (MAA mucus concentration) and were subsequently exposed to UVB light to induce DNA damage. Following exposure, the fish were either placed under conditions that allowed for photorepair (UVA and blue light) or were left in a dark environment to prevent photorepair. Cell damage was quantified histologically and DNA damage was quantified by an ELISA assay using antibodies specific to CPDs. Cell damage was highest in fish that lacked MAA protection and that were prevented from photoreactivation. In contrast, the presence of MAAs, or photoreactivating light significantly reduced DNA damage. Our results show, for the first time, that reef fish have the ability to photorepair DNA damage, likely via the enzyme photolyase, thus demonstrating the vital protecting role of mucus sunscreen compounds for tropical reef fish.

13A Fish
Tuesday 10 July, 1000, Hall A

Small scale movements and habitat preferences of *Lutjanus fulviflamma*

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The movement patterns and habitat preferences of *Lutjanus fulviflamma* (Forsskål,

1775) have been determined using acoustic telemetry. Juveniles of *L. fulviflamma* are commonly found in shallow habitats (mangrove, seagrass beds) whereas adults are schooling in deeper parts in association with coral reefs. Twelve adults (mean TL:19.0; SD:1.7) and four juveniles (mean TL:13.4; SD:0.3) have been tagged at two shallow locations nearby Ouano MPA (New Caledonia, established in 2004). Active tracking during day and night time shown a high fidelity of *L. fulviflamma* to one to two sites (coral patches) and movements ranged from few meters to more than a kilometre for the two size classes. Differences in movement patterns between day and night have been observed, with individuals of both size classes leaving their day time shelter to venture onto shallow soft bottom areas during the night. Gut analysis revealed that 75% of the fish caught in the early morning had a stomach at least half full, whereas all the fish caught in the evening had empty stomachs, suggesting that *L. fulviflamma* makes nocturnal excursions over soft bottom habitats for foraging purposes. These results provide relevant information on the ecology of *L. fulviflamma* and may help to improve the management of Ouano MPA which encompasses limited mangroves and shallow seagrass areas, habitats of high importance especially for early life stages of many species.

13A Fish
Tuesday 10 July, 1200, Hall A

Damselfish distribution in Southwestern Atlantic reefs: local and latitudinal effects

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We investigated the extent to which the distributions of damselfish (*Stegastes* spp.) are determined by wave exposure, depth and/or substrate quality, comparing tropical and subtropical reefs of the Brazilian Coast. *Stegastes fuscus* and *S. variabilis* densities, in general, were respectively higher on sheltered and exposed sites, with patterns being consistent in both systems. Depth variation was also a strong predictor, explaining damselfish distribution patterns on tropical reefs; mean density was significantly higher in shallow habitats for *S. fuscus* and deep habitats for *S. variabilis*. On subtropical rocky reefs, vertical zonation of benthic communities was variable at the scales of hundreds and tens of meters. This provided suitable habitats for *S. fuscus* at all depth strata. *S. variabilis* was more abundant at shallow depths in exposed sites, whereas *S. pictus* occurred at greater depths, not strongly affected by wave energy. On a smaller scale, there were also preferences for microhabitat features. *S. fuscus* was associated with territories that offered better resources with respect to ideal refuge and food, such as hole sizes between 5-10m² and cover of filamentous algae. *S. variabilis*, a smaller-sized species, was associated with descriptors conferring higher protection against predators on subtropical reefs, such as urchins and higher bottom rugosity at shallow depths. However, on tropical reefs, macroalgae dominated bottoms seemed to be selected for by this species. Moreover, the observed distribution patterns also indicated that inter-specific competition may play an important role in habitat partitioning, as dominant *S. fuscus* adults control territorial areas that are virtually never overlapped by *S. variabilis*.

13A Fish
Tuesday 10 July, 1030, Hall A

Temporal variation of fish assemblages in sea grass habitats in the Chuuk Lagoon, Micronesia

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Temporal variation of fish assemblages in seagrass habitats in the Chuuk Lagoon, were determined by analyzing monthly samples collected using a seine net from Aug 2009 to Aug 2011. A total of 10,444 individuals (36 species; 18 families) were recorded. *Atherinomorus lacunosus* (61.6%) was the most dominant species. Subdominant species were *Spratelloides elicatulus* (22.5%), *Aeoliscus strigatus* (2.6%), *Hemiramphus far* (2.0%), *Halichoeres richmondi* (1.69%), *Sphyraena forsteri* (1.61%), and *Caranx sexfasciatus* (1.60%). Significant differences were observed in relative abundance and species richness among months. Juveniles of *H. far*, *H. richmondi*, *S. forster* and *C. sexfasciatus* represented more than 90% of all individuals. The results suggested that seagrass beds of Chuuk Lagoon were used as a nursery area by juveniles. The present work provides information on the range of temporal variation in fish species composition and number of fish species, found in tropical seagrass habitats.

13A Fish
P113

Modeling landscape drivers of reef fish habitat use from splitbeam and multibeam sonar surveys

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Coral reef ecosystems are topographically complex environments. This structural heterogeneity influences the distribution, abundance and behavior of marine organisms, including reef fish. A better understanding of these animal-environment relationships is required for managing fisheries resources and designing marine protected areas effectively. In order to begin to fulfil this management need, multibeam and splitbeam echosounders were used to acquire spatially and temporally coincident information describing the bathymetry and quantifying fish populations at several locations in the U.S. Caribbean. Seven metrics were derived from the multibeam bathymetry surface to describe the complexity of the seafloor at multiple spatial scales. Spatially-explicit models were used to identify the seafloor complexity metrics and spatial scales that explained the majority of variance in fish sizes, abundances and distributions as measured by the splitbeam echosounder. Outputs from these models were similar to those quantified in previous landscape studies, which focused on shallow-water coral reef environments. In the future, these models may also be used to predict spatial patterns in fish sizes and abundances for areas that have not been surveyed by divers or using fisheries acoustic technologies. Overall, this study demonstrates the utility of, and capacity for, multibeam and splitbeam echosounders to produce important baseline information and as decision support tools for fisheries managers, ecosystem-based management and marine spatial planning.

13A Fish
P239

Multi-scale demographic trends in an introduced Hawaiian reef fish

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Identifying the appropriate spatial scale to measure ecological mechanisms can be difficult, and this is arguably a large gap in understanding the population dynamics of coral reef fishes. Multiple factors operating at different spatial scales affect local populations of reef fish, such as ocean current patterns at a broad scale and competition at a fine scale. This study utilizes a unique opportunity to collect large sample sizes of a coral reef fish species across the Hawaiian Archipelago. Collections occur as a result of a grass roots effort to remove an invasive predatory fish, the peacock grouper *Cephalopholis argus*, which was introduced into Hawaii in the 1950s. Otolith ageing techniques were employed to describe age and growth, and that information combined with length frequency distributions from underwater visual surveys was used to estimate population size structure by location. These factors, measured at different locations, were then compared to assess the individual effects of temperature, habitat, productivity, latitude, and conspecific density on demographic responses of *C. argus*. This study highlights the importance of considering variability in demographic parameters in a coral reef fish for population assessments. Further, this is a step towards understanding the variation of demographic parameters, and how this relates to physical and biological processes that occur on multiple spatial scales.

13A Fish
Tuesday 10 July, 1630, Hall A

Food-web in *Stegastes planifrons* and *Stegastes adustus* territories (Pomacentridae)

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The threespot damselfish (*Stegastes planifrons*) and the dusky damselfish (*Stegastes adustus*) are two abundant damselfishes of Caribbean coral reefs. Referred as 'farmers', both species cultivate algal turf inside their territories, aggressively defended from other herbivorous fishes. These farming activities play an important role in the control of algae dynamics on coral reefs. In Guadeloupe, we studied the trophic relationships between both damselfish and the components of their respective territory, by stomach content and stable isotopes analyses ($^{15}N/^{14}N$ and $^{13}C/^{12}C$ ratios). In terms of ingestion, *Stegastes adustus* presented a more pronounced herbivorous tendency than *Stegastes planifrons*, which consumed mostly harpacticoid copepods. Food sources consumed by both fishes came from the benthic habitat inside each *Stegastes* territory, which avoids food competition between the species. Assimilation rates of each food source calculated with linear mixed models, were similar between both species, reflecting comparable metabolisms. Three major food sources were detected in diet assimilation: algae and turf cultivated inside territories,

benthic invertebrates present inside turf mat, and biofilm composed of organic detritus, bacteria and diatoms. This last item was not found inside stomach contents due to its reduction into tiny ground particles, but represents an important nutritional compartment for both fish species. The same isotopic profiles of *Stegastes planifrons* and *Stegastes adustus*, have been found at both sites. However, at one site, higher nitrogen signatures, associated with higher algal specific richness and lower food quality (in term of biochemical concentrations and C:N ratios), may reflect an anthropogenic influence.

13A Fish
Tuesday 10 July, 1730, Hall A

Patterns of reef fish density and biomass in the Brazilian Province

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Quantitative macroecological research is vital to understand large scale ecological processes. The extensive Brazilian coast (8000 km) and its oceanic islands (the Brazilian biogeographic province) provide a huge gradient for macroecological analyses. This includes a diverse set of ecosystems, forming a tropical-subtropical gradient. Interestingly, this entire gradient is restricted to only one jurisdiction policy regime. We investigated patterns of biomass and density of reef fishes along the Brazilian coast and oceanic islands with emphasis on trophic groups. A large database with standardized visual censuses (20x2 m) for reef fishes, was analyzed considering the following factors: benthic diversity, isolation and protection status. Total biomass and density of reef fishes are higher in oceanic islands compared to coastal systems. Macrocarnivores and roving herbivores are the trophic groups which contributed most to this result. Isolation and protection explained almost all of the patterns found. However, contribution of functional groups in each oceanic island is markedly different, being highly determined by the isolation 'filter' and available reef area. Biomass and density of planktivores were two to three times higher on oceanic islands compared to the coast. Biomass and density of functional groups of herbivorous fishes changed significantly among islands, as well as between tropical coral reefs with subtropical rocky reefs. Biomass of omnivores increases with latitude and sparids apparently function as the major algae-feeders in subtropical reefs. Beyond overfishing, differences in functional groups among different reefs are driven by colonization patterns and phylogenetic affinities, and/or species affinities to water temperature.

13A Fish
Tuesday 10 July, 1745, Hall A

Comparing fish assemblages in oceanic islands of the eastern Pacific

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The Revillagigedo Archipelago and Clipperton atoll are located in the tropical Eastern Pacific, and represent the westernmost limits of the Oceanic Island Province. Both areas have rich and abundant fish communities, but to date only systematic listings and occasional observations about the species have been published. The objective of this study was to analyze community structure and assess the similarity in fish assemblages of both regions. Visual censuses (25 x 4 m transects) were done at depths from 5 to 30 m on three islands of the Revillagigedo Archipelago (Socorro, San Benedicto and Roca Partida) and at Clipperton, and for each one (N=102), ecological indices (density (ind/m^2), richness, Shannon-Wiener diversity and Pielou evenness) were calculated. The data were compared with ANOVA, an nMDS was applied to determine similarity among islands, and the SIMPER test defined representative species for each site. The results showed significant differences in all indices, with Roca Partida being the location with higher abundance and richness (due to the presence of pelagic species that appeared in high numbers) and with the lowest evenness (caused by the dominance of *Stegastes leucorus*, *Paranthias colonus* and *Xanthichthys mento*). The ordination did not identify clear differences in composition among islands, although Clipperton has a somewhat particular fauna that includes the endemics; *Thalassoma robertsoni* and *Stegastes baldwini*. In conclusion, community structure and composition are relatively similar among islands because they belong to the same biogeographic province; however, Clipperton can be distinguished due to the influence of its endemic species.

13A Fish
Tuesday 10 July, 1015, Hall A

Interconnectivity of reef systems of migratory fishes in the Philippines

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Understanding the interconnectivity of organisms among different habitats is essential for adaptive management of coastal ecosystems, particularly to determine the suitable size for an MPA and its component habitat structures. To clarify habitat use patterns of fishes, visual censuses were conducted in coral reefs, seagrass beds, and mangrove areas at Puerto Galera (northern Mindro Island) and Laguindingan (northern Mindanao Island) in September and March 2010-2012. Fishes exhibited two different strategies for habitat use, inhabiting either a single or several habitats. Some of the fish with the latter strategy (e.g. *Lutjanus fulviflamma*, *Siganus fuscescens*) showed habitat shifts from mangrove areas or seagrass beds to coral reefs, with growth. Moreover, adult *Lethrinus harak* made forays into the seagrass beds to feed as well. Based on these habitat use patterns, we then tried to confirm whether or not size of MPA (*ca.* 22 ha) in Laguindingan was appropriate for conservation of migratory fishes. Nine acoustic receivers were set inside and outside the MPA and migrations of >20 acoustic-tagged fish of six fishery-important species (*Lethrinus atkinsoni*, *L. harak, L. obsoletus, Lutjanus argentimaculatus*, *L. monostigma,* and *S. guttatus*) were tracked up to several months in 2011-2012. According to the results to date, most fish spent >80% of their time inside the MPA during the period, suggesting that the current MPA size is nearly appropriate for them. Moreover, *L. harak*, and *S. guttatus* frequently migrated between areas of coral reef and seagrass bed, indicating the importance of different habitats' inclusion in the same MPA.

13A Fish
Tuesday 10 July, 1145, Hall A

Thermal sensitivity and effects of global warming on coral-reef fishes

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Tropical coral reef teleosts are exclusively ectotherms and their capacity for physical and physiological performance is directly influenced by ambient temperature. This presentation highlights extraordinary thermal sensitivity in 10 species of damselfishes (Pomacentridae) from the northern Great Barrier Reef, representing evolutionary lineages from two subfamilies and four genera (*Chromis*, *Dascyllus*, *Neopomacentrus* and *Pomacentrus*). Five distinct performance measures were tested across current seasonal temperatures (23 and 29℃) and temperatures predicted by 2100 (32℃): (a) maximum swimming speed (Ucrit), (b) gait-transition speed (the speed of change from strictly pectoral to pectoral-and-caudal swimming, Up-c), (c) optimum swimming speed (the energetically most efficient speed, Uopt), (d) aerobic scope (ratio of maximum to minimum metabolic rate, ASC) and (e) total-cost-of-transport (the energetic cost of swimming at different speeds, TCOT). All species were highly thermally sensitive, with closely related species and genera varying greatly in response: Swimming ability peaked at 29℃, with 23℃ performance reduced by 18.6-41.7% and 32℃ performance by 21.3-51.3% in 6 species. Metabolic performance peaked at 23℃ in 7 species, with ASC reduced by 15.0-35.7% at 29℃ and 40.7-58.4% at 32℃, whilst cost-of-transport increased by 40.1-70.5%. Field comparisons demonstrate that reef fish are energetically optimized for occupying particular habitat flow conditions and temperatures with habitat use limited by lowest seasonal performance. Furthermore, expected 32℃ temperatures will leave multiple species with less performance capacity than required to overcome the water flows commonly found in their respective coral-reef habitats. Unless adaptation is possible, significant changes in fish assemblages may occur under IPCC predictions of global warming.

13A Fish
Tuesday 10 July, 0930, Hall A

Do butterflyfish maintain their partner for a life time?

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Butterflyfish (Chaetodontidae) are common coral reef fish in tropical reef areas. Almost all species in this family form a pair composed of one male and one female, and guard their territory. The present survey studied the age and growth of *Chaetodon vagabundus*, to estimate the timing of pair-forming, and to reveal the continuity of a pair over time. Pairs

ranging across several size classes, were collected using trammel net, spear gun, and hand net. The differences in standard length between individuals in a pair, were less than 12.0 mm, indicating individuals are biased towards choosing a mate of a similar size. Using sections of otolith, the maximum age for female and males were estimated to be 19 and 17 years, respectively. No difference in growth patterns could be detected between males and females, and fish older than 4 years didn't grow noticeably. Pair forming appeared first at an age of 2 years. Females and males didn't choose partners randomly, and the differences between partners' ages were generally less than 2 years (0-1 years difference: 51.9%; 0-2 years difference: 77.8%); only a few pairs had large age gaps, up to 7 years. We suggest that *C. vagabundus* maintain their partner for a lifetime, and changes of partner only occurred when a partner was lost. This lifecycle strategy has the risk of missing the chance to gain a more competent partner. On the other hand, the fish minimises energy use for selection and competition for partners, among the same species.

13A Fish
Tuesday 10 July, 1545, Hall A

Life history characteristics of Picasso triggerfish, *Rhinecanthus aculeatus*

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The strikingly colored Picasso triggerfish, R. aculeatus is distributed in tropical and subtropical waters around the world and is strongly associated with coral reefs. On Okinawa Island, *R. aculeatus* is one of the most abundant species of the family Balistidae. Adults establish territories in reef flats with males maintaining up to several females. The spawning behavior has previously been reported but nothing is known about detailed life history characteristics. The purpose of this study was to describe age and growth from sections of dorsal spine and abdominal vertebra. To understand the reproductive biology, gonads were histologically analyzed. Mature individuals occurred from May to September, while the gonadosomatic index peaked in June and July. These results indicate that the spawning period was restricted to the warm season. Fish ranged between 20.9 and 209.5 mm in standard length, with males attaining larger sizes. Annual growth marks consisted of opaque-translucent band depositions. Small recruits were found from August in the rocky intertidal shore area. Settled recruits formed a first translucent band during the following cold season and were therefore aged 0.5 years old. The von Bertalanffy growth equation was fitted for observed length-at-age data. Maximum age for females and males was 8.5 and 9.5 years, respectively. Picasso triggerfish are viewed as one of the most successive and competitive balistids inhabiting the coral reefs of Okinawa Island. The territorial behavior, mating system and feeding habit may favor longevity, since this fish is capable of establishing territories over many years.

13A Fish
Tuesday 10 July, 1715, Hall A

Description of different color displays of Goliath Grouper on aggregations in Santa Catarina, Brazil

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Several studies around the world show that fishes from the Serranidae family display body color variations, as a tool to communicate and socialize with others fishes of the same species. These variations are more common during aggregations. The rarity, and the difficulty of observing an *Epinephelus itajara* aggregation, could be the reason that the different color displays of the Goliath grouper have not yet been described. The 'Meros do Brasil' project have been studying an *E. itajara* aggregation in southern Brazil for the last four years. During dives, the researchers recorded seven different color patterns displayed by individuals, standard, fully dark, fully light, dark body with light head, dark back and light belly, light bars, and divided face half dark half light. In addition, some instantaneous colour changes were observed.

13A Fish
P114

Sampling reef fish communities in the remote waters of Micronesia

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There has been little scientific research on reef fish communities across the extensive Micronesian archipelago. Quantitative studies in these remote atolls are constrained by accessibility and the time needed to collect valuable data. To overcome this, recent technological advances were utilised to improve efficiency of underwater visual census for coral reef fish; namely 1) closed circuit rebreathers to minimise decompression obligations and reduce potential behavioural biases associated with bubble noise, 2) stereo video cameras which improve the speed of fish counting while providing accurate measures of fish size, definition of sampling boundaries and high resolution imagery for habitat classification, 3) timed swims along transects utilising GPS tracking to standardise sampling distance and provide accurate site identification. Using these methods, four remote atolls in the Caroline Island chain from Yap to Chuuk were sampled over 7 days, where human population on each atoll ranged from uninhabited to over 500 people. Reef fish diversity, fishery targeted species biomass and length frequency was calculated from 16 sites at two depths, covering a total distance of 11.5 km of reef. Half the transects were completed using closed circuit rebreather to examine diver effects towards open circuit SCUBA. Depth stratified sampling also provided insight into the theory of deeper water refuge from artisanal fishing pressure. These results provide a useful baseline to assess change in reef fishery resources for these atolls while the novel sampling technique provided an effective and efficient method for sampling coral reef fish.

13A Fish
Tuesday 10 July, 1645, Hall A

Development and validation of non-lethal DNA sampling method for fish

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The use of population genetics to monitor fish populations in ecologically sensitive areas, is an effective management tool for understanding the structure of those populations. However, current techniques used to extract DNA from individual fish can result in unwanted injury and mortality, especially if the fish under investigation are small to medium sized teleost reef fish. The use of non-lethal sampling techniques can drastically reduce or eliminate adverse effects to the population, and are becoming increasingly necessary as studies of population genetic structure become more common. Here we report the effectiveness and feasibility of a non-lethal DNA sampling method we developed and tested on two species of teleost reef fish common to Hawaiian waters. Sixteen small sized (5-7cm) *Abudefduf* spp., and twelve medium sized (15-19cm) *Acanthurus xanthopterus* were split equally into experimental and control groups and held in a 2.75 x 4.9 x 2.4m aquaculture pen for *in situ* testing. The experimental groups of both species experienced no mortality three weeks after method testing. Collected samples were transferred to Whatman FTA paper for storage, purified using the Whatman Purification Reagent protocol, a portion of mitochondrial DNA directly amplified from the FTA paper via Polymerase Chain Reaction (PCR), and subsequently sequenced. Successful PCR resulted in 50% of our samples from both species, respectively. All subsequent sequences were a positive match to the two species of experimental fish tested.

13A Fish
P115

Functional connectivity of coral reef fish in the Red Sea

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Many commercially and ecologically important coral reef fishes, including species from the family Lutjanidae (snappers), use mangroves and seagrass beds as juvenile nursery areas before migrating to coral reefs as adults. However, few studies have examined the functional connectivity among essential coral reef fish habitats at the seascape level. We quantified the relative contribution of coastal wetland and reef habitats to Ehrenberg's Snapper (*Lutjanus ehrenbergii*) populations on coastal and oceanic coral reefs in the Red Sea using a new otolith essential amino acid $\delta^{13}C$ analysis method for tracking fish migration. Our isotope data revealed tremendous plasticity in juvenile nursery use, while traditional abundance surveys grossly misrepresented the importance of certain habitats and completely missed others. We show that a habitat can still be a valuable juvenile nursery and contribute individuals to the adult population, even if juveniles were not visually abundant in that habitat. Contrary to the current paradigm of a simple progression from wetlands to reefs, seascape configuration played a critical role in determining migratory connectivity among essential habitats. Our results provided the first direct measurements of a remarkable migration by juvenile snapper from coastal wetlands to coral reefs at least 30 km from the coast, and from a shelf island across deep open water to oceanic reefs. Identifying essential habitats and

preserving these functional linkages is likely necessary to promote ecosystem health and sustainable harvest on coral reefs.

13A Fish
Tuesday 10 July, 1115, Hall A

Generalisation of learned predator recognition in coral reef ecosystems

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Learnt predator recognition provides animals with an adaptive mechanism to rapidly adjust to current levels of predation risk. Prey may be able to reduce the costs associated with learning if they can generalise their anti-predator response to cues from a known predator, to cues of closely related predators that are unfamiliar to the prey. However, the extent to which individuals generalise is dependent on their ability to accurately assess their chances of correctly identifying another predator, given the information available to them. Here we investigated how the information available from different cues (visual and chemical cues) affects the ability of prey to generalise predator recognition and whether different information allows prey to distinguish between predators and non-predators when generalising recognition. Damselfish, (*Pomacentrus moluccensis*) conditioned to fear the moon wrasse (*Thalassoma lunare*) using the various cues, were then tested for their response to *T. lunare*, a congeneric predator (*T. hardwicke*) and non-predator (*T. amblycephalum*), a confamilial predator (*Coris batuensis*) and non-predator (*Halichoeres melanurus*), a distantly related control predator (*Pseudochromis fuscus*) and a relevant control (saltwater or blank card). Our results highlight that reef fish are cautious when generalising predator recognition, in keeping with the predictions. Additionally, the results show how fish generalised recognition varied depending on the information available to them from the different cue types.

13A Fish
Tuesday 10 July, 1530, Hall A

Temporal habitat utilization patterns by reef fishes in GTMO, Cuba

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It has been demonstrated that habitat characteristics play an important role in determining reef fish assemblages. However, temporal differences have largely been overlooked. This investigation examined how temporal changes influenced the functional relationship between reef fishes and habitat complexity. Secondly, it was possible to make a comparison between protected verses semi-protected reef communities. All sites are located in the territorial waters of the U.S. Navy Base, Guantanamo Bay, Cuba thus in comparison to the wider Caribbean are underutilized: protected and semi-protected. The study focused on fringing reefs immediately to the west and east of the mouth of Guantanamo Bay. Sites were located between the 0-60 feet depth range and chosen through investigator knowledge and satellite imagery analysis. Benthic data were recorded digitally and analyzed by point count methodology. To ensure uniformity, the camera was mounted on a frame attached to a quadrat (1 x 0.66m). Sites consisted of photo-quadrats arranged in a square 3 x 3 pattern, 5 m long and 5 m wide. Fish assemblages were assessed using SCUBA and all fish species observed within the boundaries of each site recorded during a 3 minute period. Not only does this examination provide a greater understanding of spatial and temporal habitat utilization by reef fish assemblages, it also provides a unique comparison of reef-associated fish communities in a largely unstudied and protected reef system.

13A Fish
Tuesday 10 July, 1215, Hall A

Demographic plasticity in hindtail grouper in American Samoa

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We examined the sex-specific and the inter-island demography of the hindtail grouper *Cephalopholis urodeta*, the most common coral reef grouper, in American Samoa. The size and age distributions suggested protogynous monandric hermaphroditism consistent with a previous study. The distributions also implied that timing of sex change was flexible occurring across a wide range of sizes and ages. Sex ratio indicated pair groupings and an absence of sex-biased ratios expected for a protogynous hermaphrodite. Growth rate was the highest reported for any grouper, while longevity one the lowest (10 years). Males had significantly

higher growth rates, and were bigger and older than females. Although longevity did not differ between sexes, males had significantly higher mortality rates than females. There were significant differences in size and age distributions and longevity among the islands. One island had significantly smaller, younger and shorter-lived groupers indicating demographic plasticity even across a small geographic scale. Differences in fishing pressure might account for these discrepancies. These demographic differences suggest the need for island-specific management strategies for the fishery of the hindtail grouper in American Samoa.

13A Fish
Tuesday 10 July, 1245, Hall A

Local adaptation to climate change: fish physiology across latitudes

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Tropical ocean temperatures have warmed significantly over the past 50 years and are predicted to increase a further 3°C by 2100. Elevated temperatures can alter distribution patterns and compromise reproductive output of reef fishes. The mechanistic explanation relates to how temperature influences the physiological scope for oxygen transport. An organism's entire range of oxidative metabolic activity or aerobic scope is the difference between their resting (MO_2Rest) and maximum (MO_2Max) oxygen consumption. Aerobic scope should be optimized for the temperature range (Topt) an organism generally encounters and can thus be used as a tool to investigate different species' sensitivity to ocean warming. We compared the aerobic scope of damselfish and cardinalfish species living at a near-equatorial location (~2°S latitude) in Papua New Guinea, where seasonal temperatures only span ~3°C, to results from previous studies conducted on populations living at higher latitudes on the Great Barrier Reef. Until now, metabolic sensitivity of equatorial reef organisms had not been investigated. The underlying hypothesis is that low-latitude populations are more sensitive to rising temperatures than higher latitude populations because they are adapted to a narrower range of temperatures in their local environment. Aerobic scope generally declined with rising water temperature, and most species appear to already be living at or above their optimal thermal temperatures. Results from this study indicate that low-latitude reef fish populations are more sensitive to ocean warming than higher-latitude populations. Minor temperature increases (2-3°C) could result in population declines and the potential for large-scale redistribution of equatorial species.

13A Fish
Tuesday 10 July, 0945, Hall A

Skin cancer in butterflyfish and surgeonfish on the reefs of Hawai`i

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Understanding marine disease is increasingly important, yet baseline disease data are lacking for most marine communities. In Hawaii, some species of butterflyfish have protrusive skin tumors and the endemic surgeonfish, *Ctenochaetus strigosus*, has obvious patches of skin discoloration. Little is known about reef fish disease in the Hawaiian islands (HI), so we completed visual surveys in the main (MHI) and northwestern Hawaiian Islands (NWHI) to determine the distribution and prevalence of disease in surgeonfish and butterflyfish. Within the MHI, five species of butterflyfish were affected with tumors with one species, *C. multicinctus*, having the highest overall prevalence (7.5%). Affected butterflyfish were found in seven out of fifteen surveys (frequency of occurrence=46.7%) and had an overall tumor prevalence of 1.6% (n=958 fish). In contrast, within the NWHI no affected fish were found out of 21 surveys conducted at nine different atolls/islands (n=968 butterflyfish). Tumor-affected surgeonfish (*C. strigosus*) were found in both the main (40% of the surveys) and northwestern Hawaiian Islands (66.7% of the surveys). Overall disease prevalence was similar being 2.9% in the MHI (n=1778 fish) and 3.2% in the NWHI (n=1556 fish). Histology revealed the tumors to be pigment cell tumors (chromatophoromas, xanthophoromas) that were locally invasive into underlying muscle in both butterfly and surgeonfish. Presently, the causes of these tumors are unknown, but their clustered distribution suggests habitat may play a role.

13A Fish
P116

Multiple-scale factors influencing agonistic and feeding behaviour on Brazilian Damselfish

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Local and large-scale factors influence fish feeding behaviour and territoriality. For instance, local density-dependent processes might structure reef fish communities, while temperature at the large scale, affect their thermo-dependent metabolism. Damselfishes are good models to evaluate such relationships in reef systems, and may contribute to clarification of the influence of both local and large-scale factors on fish behaviour. The Brazilian Damselfish *Stegastes fuscus*, is an endemic reef fish species widely distributed along the Brazilian coast, from 3°S to 27°S, thus allowing wide latitudinal comparisons. How are agonistic interactions (chase rates) affected by conspecific density (local-scale factor)? How does feeding behaviour (bite rates) respond to sea surface temperature (SST; large-scale factor)? To address such questions we quantified chase and bite rates of *S. fuscus* adults per 3 min focal observation at four reef sites (two tropical and two subtropical reefs) along the Brazilian coast, comprising their entire distribution. The chase rate was density-dependent only when more than 8 individuals per 10 sq.m. were recorded (tropical reef; 16°). Territoriality might increase with intense conspecific resource partitioning. We also detected differences in bite rates among the four sites with bite rates increasing with SST, from subtropical to tropical reefs, supporting the temperature effect on fish metabolism. Our results reveal that reef fish behaviour is affected by both local and large-scale factors, although disentangling such influences remains a challenge. Prediction studies on global warming effects on communities should integrate behaviour studies into their framework.

13A Fish
P117

A comparison of field methods for assessing boldness in fishes

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Boldness represents the propensity of an animal to take risks, and reflects a growth/mortality trade-off. Many techniques are used to assess the boldness of individual animals using variations on novel-object or novel-environment tests. However, it is unknown how these measures compare or whether they assess behaviors in relation to an ecological aspect of fitness. This study compares individuals in four variations of these tests, their relationship with survival, and inter-observer consistency. Newly metamorphosed damselfish, *Pomacentrus moluccensis*, were placed onto patches of cleared habitat. Individual behaviors were quantified under four tests: overall activity within and latency to being released into a novel environment, and reactions to threatening and benign novel objects. Individual survival was monitored twice daily for 2 days, after which ~40% of fish died. No single measure adequately described the boldness-survival relationship. However, a combination of novel environment tests did, encompassing many measures which influenced survival (latency at release, maximum distance ventured, and feeding rate). Observer variation was low for most measures except distance moved and threat tests. Measures which described natural behaviors of an individual within a new environment, were useful for assessing the boldness-survival relationship. Novel object tests were more difficult to quantify and provided limited additional value.

13A Fish
Tuesday 10 July, 1500, Hall A

13B The changing role of fishes in coral reef ecosystems

Fishing down nutrients: altering coral reef ecosystems from the bottom up

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Effective management of marine fisheries has emerged as one of the world's foremost conservation challenges. While implications of overharvesting marine fisheries have been well studied, particularly from the top-down perspective, (i.e. trophic cascades associated with the removal of top predators) alternative frameworks may be necessary to provide a more complete understanding of the ecosystem-level consequences of this perturbation. Animals play an important role in the cycling (via excretion) and retention (via biomass) of nutrients at the ecosystem scale, with important feedbacks on primary production. These processes are critical in

oligotrophic ecosystems with relatively little allochthonous nutrient input and high animal biomass, such as coral reefs. Using a Bayesian approach, we combined bioenergetics modeling with empirically derived excretion rates and body stoichiometry from 875 individual fish and invertebrates, including 92 species, to estimate nutrient storage and flux by coral reef fishes. These findings were modeled onto datasets of community composition of coral reef fishes in marine protected areas and adjacent non-protected areas in The Bahamas Archipelago. Because species deviate substantially in the amount of nutrients they recycle and store, this approach reveals that overfishing via alteration of population size and community composition decreases the capacity at which the ecosystem can store and cycle nutrients, a ramification that would otherwise be overlooked using biomass and/or abundance measurements alone. Reductions in this nutrient capacity of an ecosystem may have important legacy effects on coral reefs whereby long-term constraints on primary production may reduce secondary production with important implications for fisheries management and conservation.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1645, Hall D

Use of remote video to access cleaning interactions

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Cleaning interactions are characterized as an important ecological service offered by cleaner organisms to a great diversity of clients. Despite the high influence of cleaning interactions on reef fish communities, few species of cleaners are well studied in the Caribbean and Indo-Pacific. On Southwestern Atlantic reefs, few cleaner reef fish have been studied with respect to cleaning activity patterns and human impacts. In this study, we aimed to investigate the possible effect of diver presence on frequency and duration of interactions among Brazilian endemic cleaner fish *Elacatinus figaro* and their reef fish clients. Few sites are protected along the Southeastern Brazilian coast (4°N-28°S), resulting in diver avoidance by reef fish. As a result, to obtain an unbiased record of the client community, we used remote video to observe cleaning events. Cleaning stations were subjected to two treatments: remote stationary video and subsequently, stationary video with the presence of a diver. Both methods presented similar registers of client community composition, and similar number and duration of interactions, validating the efficiency of remote video. No effect of diver presence was detected on species which are targeted by spearfishing. As large and big fishes are rare in the study area, the continued use of remote video could improve their detectability by increasing total sampling time with no need for a diver. In summary, the remote stationary video has been shown to be a precise and non-time-consuming technique, and is highly recommended for use in behavioral studies.

13B The changing role of fishes in coral reef ecosystems
P120

Are habitats important in mediating range shifts in tropical fishes?

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Substantial shifts in the range of tropical fishes into south eastern Australia are predicted for the near future. Such distributional changes are associated with rapid intensification of the Eastern Australian Current, with waters in SE Australia warming at the greatest rate in the southern hemisphere. Over-winter mortality currently constrains establishment of permanent populations of tropical fishes in NSW. However, relatively consistent annual recruitment through the austral summer (November to April) allows the exploration of the importance of temperate habitats in mediating range shifts of tropical fishes. Here, timed underwater visual surveys were used to examine density, richness and composition of tropical fish assemblages in habitats along the NSW coastline. Surveys were conducted on latitudinal, broad and fine scales. Butterflyfishes, surgeonfishes, damselfishes and wrasses composed 99.99% of tropical fishes observed. At the latitudinal scale richness reduced from north to south. At the broad scale, greater densities and more rich assemblages were found in estuaries than adjacent reefs. At the fine scale, tropical fishes were almost exclusively associated with sea urchin barren habitat within sheltered areas. Trophic composition differed on broad-scales, with greater proportions of invertivores in estuaries than reefs, whilst greater proportions of planktivorous fishes were found in reefs than estuaries. These results suggest features of temperate regions at multiple scales will be vital in mediating survival and potential establishment of tropical reef fish populations in temperate regions.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1030, Hall D

The changing role of fishes on reefs: an evolutionary perspective

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Fishes and coral reefs have a common history that spans over 380 million years. During this time their interrelationships have changed from one of indifference to one of mutual interdependency. We examine the evolution of this increasingly complex interaction, looking at both fossils and molecular phylogenies, and examine how this history has shaped the changes we are seeing on today's coral reefs. The first steps in this shared evolutionary history are in the Devonian where we occasionally see the close juxtaposition of reefs and fishes with a relationship based on spatial proximity not ecology. The ecological interactions develop slowly, with the first fish durophages in the Triassic, followed by the origins of herbivory, diurnal precision feeding and nocturnal planktivory in the Late Cretaceous or Early Tertiary. In more recent times we have seen the evolution of more specialized and more closely linked trophic and ecological relationships between fishes and reefs. Many of these relationships have been established over the last 20 Ma. The ecological interactions between fishes and coral reefs have been ratcheting up incrementally over the last 380 Ma leading to the modern configuration. Today, anthropogenically-induced changes threaten to turn back the evolutionary clock leading to a degraded, depauperate, and ultimately less interdependent system. A system that took million years to develop is unravelling and it is those forms with the tightest dependencies that are suffering most. For reefs and reef fishes, the future appears to be one of increasing opportunism and self-sufficiency.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1000, Hall D

Habitat use and distribution patterns of the monocle bream (Nemipteridae)

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Nemipterids are ubiquitous fishes on Indo-Pacific reefs. Despite their prevalence, however, little is known about their ecology, and trophic role on coral reefs. The aim of this project was to investigate the ecology of the nemipterid *Scolopsis bilineatus* on the Great Barrier Reef. Mensurative and manipulative methods were used to provide a holistic view of habitat use. Data on demography, diet and diel feeding behaviour were used to augment information on distributions and habitat use. Distributions were influenced by processes within reefs including depth, exposure, and reefal environment. Fine scale distributions were influenced by reproduction, with adults commonly occurring in reproductive pairs. Habitat affiliations were considered at multiple spatial scales, and variation among microhabitats was found to be important. Adults occupied shelter sites most frequently, and strong evidence was found for site fidelity. At night, they dispersed onto sandy substrates to feed. Juveniles were diurnal, and occupied rubble and sand microhabitats. Behavioural observations and an experiment showed plasticity in feeding behaviour. Fish responded to disturbance, and opportunistic multi-species foraging associations occurred. This behaviour may significantly supplement the acquisition of nocturnal prey. Knowledge of these behavioural patterns facilitated greater understanding of static distributions and trophodynamics. Nemipterids are conspicuous microcarnivores that forage on benthic organisms. This study demonstrated the need for a holistic approach for studies concerning habitat use and distribution patterns of fishes.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1035, Hall D

The function of pair-formation in the rabbitfish *Siganus doliatus*

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Herbivorous reef fishes are generally acknowledged to be crucial for coral reef resilience. Within the herbivorous family of rabbitfishes (f. Siganidae), pair formation is a common behavioural trait in several species, while other species can be found in large schools. In this study, acoustic telemetry, visual counts and behavioural observations were combined to evaluate the nature and the underlying purpose of pairing in *Siganus doliatus*, an abundant and important siganid on inshore reefs of the Great Barrier Reef. Visual censuses indicated that pair formation is common (67.4% of all individuals) and increasingly prevalent with increasing body size (93.7% in specimens >20 cm). Acoustic telemetry revealed that paired individuals exhibited high mate fidelity with small, extensively overlapping home-ranges (1.53 ± 0.13 ha, with a core area of activity of 0.31 ± 0.03 ha). The ranges of pairs diverged by only

0.22 ± 0.15 ha. Although high pair fidelity and increasing prevalence of pair formation with size suggest monogamous mating as the purpose of pair bonds, reproductive function is unlikely, as a high proportion of homosexual pairs, of both genders, were found (25% of all pairs). No assessed behavioural trait served as an explanation for pairing. We suggest that pair formation might be a form of predator avoidance strategy associated with highly selective feeding behaviour in these fishes.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1750, Hall D

Mesocarnivorous fishes facilitate macroalgae and suppress corals in a Caribbean reef ecosystem

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Mesocarnivorous fishes (e.g. snappers, grunts, goatfish) can facilitate coral growth by vectoring nutrients to reefs from nearby ecosystems via daily migrations. However, as coral abundance declines on many reefs and opens space for fast-growing macroalgae, this nutrient subsidy may no longer benefit reefs. We surveyed forereefs in the Florida Keys, USA to test the relationship between fish community structure and benthic community structure. Mesocarnivore biomass was the strongest predictor of macroalgal cover, with algal cover increasing as mesocarnivore biomass increased. Herbivore biomass showed a negative, but weak, correlation with macroalgal cover. Increasing mesocarnivore biomass resulted in increased delivery of nitrogen and phosphorus, as shown by increasing nitrogen and phosphorus concentrations in tissues of the alga *Dictyota menstrualis*. In fact, bioenergetics modeling showed that mesocarnivores represented the most important source of nitrogen on these reefs, delivering 33 times more nitrogen than all other biotic and abiotic sources of nitrogen combined. More importantly, mesocarnivore biomass also showed a strong negative correlation with the density of juvenile corals. The increased cover of macroalgae resulted in more direct competition between algae and corals as mesocarnivores increased, which likely drove this relationship. Thus, mesocarnivores can be important vectors of limiting nutrients to reefs, and these nutrients can stimulate primary production, increase algal biomass, and decrease juvenile coral abundance. The loss of coral cover to climate change and disease in the Florida Keys likely has altered these consumer-mediated nutrient subsidies from an important facilitator of reef health to a potential driver of reef decline.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1115, Hall D

Does habitat fragmentation restrict coral reef fish movements?

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Acoustic telemetry was used to describe movements of two commercial reef fish species (51 fish; *Lethrinus atkinsoni* and *Lutjanus fulviflamma*) within the lagoon seascape of Ouano (New Caledonia). The study site (48 km²) includes a large MPA that extends from the coast to the barrier reef. Different ecosystems are found in the study area: mangrove swamps, soft bottoms, seagrass and algal beds, and different coral reef formations. 92% of tagged fish were redetected in the area. Preliminary results show that 74% of them displayed dispersive patterns. The distance covered ranged from a few hundred meters to 23 kilometers in 6 months (54% > 1200 m). 40% of the fish (two species) were detected in more than one ecosystem, generally reefs and soft bottoms, sometimes several kilometers apart. These first results suggest that the two studied species can travel long distances over short time periods (few weeks or months), that habitat fragmentation do not restrict their dispersion and that the ecosystems studied in Ouano are connected. 6 fish from the reserve (12%) were detected in the fished area. These movements involved 1 to 4 changes of habitat, and movements of several kilometers within the lagoon. These results suggest that the studied MPA could benefit the adjacent fished area over kilometers despite habitat fragmentation. If the current trends are confirmed, the design of Ouano MPA could be optimized.

13B The changing role of fishes in coral reef ecosystems
P118

Feeding plasticity of reef fish

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Reef fish play important ecosystem functional roles, and the importance of one such role, herbivory, has been well documented. The assessment of reef health, vulnerability and resilience are mostly achieved by estimates of the total biomass held within specific functional guilds and the number of species that add to this biomass. The ability to assess functional biomass depends largely on our assignment of

a species' fundamental niche. The species *Plectroglyphidodon lacrymatus* is conventionally classed as a territorial herbivore, and *Chaetodon baronessa* as an obligate *Acropora* corallivore. We hypothesised that the degree to which the species depend on herbivory and corallivory respectively, varies across habitat quality gradients. Research was conducted on three reef sites of varying quality within the Wakatobi Marine Park, South East Sulawesi, Indonesia. *P.lacrymatus* switched to planktivorous feeding at two of the reefs. The expansion in the realised niche occurred on the same two reefs where: higher frequencies and durations of inter/intra aggressive behaviours were recorded, territory volume was also significantly smaller and the abundance of competitors was higher. The results suggest that competition was the driver for niche expansion. Both behavioural and isotope data found *C. baronessa fed* on a broad range of coral genera on sites where *Acropora* was less abundant. Algal feeding also took place on sites with low coral cover. Therefore niche expansion for this species seemed to be driven by resource availability. Determining fish response to habitat change is the key to understanding reef resilience and the future management of reefs.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1530, Hall D

Seasonal changes to the feeding behaviour of Butterflyfishes on a high-latitude coral reef

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Changes in water temperature can influence the behaviour, performance and physiological condition of coral reef fishes. On high latitude subtropical coral reefs, seasonal fluctuations in sea surface temperature are likely to result in significant impacts to individuals, with flow-on effects to the overall dynamics and functioning of the system. Despite the potential importance of seasonal temperature fluctuations in structuring coral reef fish communities, specific impacts to the behaviour of coral reef fishes have rarely been measured. Therefore, this study quantified seasonal changes in the feeding behaviour of corallivorous butterflyfishes at Lord Howe Island, Australia, the world's most southerly coral reef. We found that the feeding rates of butterflyfish (*Chaetodon tricinctus*, *C. lunulatus*, *C. melannotus*, *C. plebius* and *C. trifascialis*) were significantly lower during winter months compared to summer, and that the foraging activity of butterflyfishes was also lower in winter with individuals visiting fewer colonies. This suggests that metabolic rate suppression is an important mechanism employed by coral reef fishes to survive natural seasonal fluctuations in water temperature.

13B The changing role of fishes in coral reef ecosystems
P119

Human influence on fish biodiversity facets in the Pacific

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Coral reefs support over two million species and supply 10% of the fish consumed by humans. However they are vulnerable to anthropogenic pressures that imperil the provision of such goods and services. To assess human impacts on fish community structure, we implemented, probably for the first time at an ocean scale, a multifaceted analysis examining species richness, biomass and functional and phylogenetic diversity. We compared the patterns for two conspicuous groups of fishes using 1553 visual transects across 17 countries in the Pacific Ocean: the seldom-exploited butterflyfishes versus the heavily exploited parrotfishes. We implemented Boosted Regression Tree models to rank 22 variables related to habitat, biogeography and local socio-economic conditions. We found that functional (FD) and phylogenetic diversity (PD) of parrotfishes were primarily influenced by socio-economic category (~47%) while species richness (~24%) was mostly influenced by habitat (48%) and biogeographic (~29%) categories. The annual catch of fish per unit surface was the most influential variable: an increase from 0.07 to 78.17 T/km² reef/year induced a decrease of FD and PD by respectively ~32% and ~35%. This study indicates that limited human impacts can have a strong negative impact on the phylogenetics diversity of reef fish communities and undermine the diversity of functions that they can perform.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1200, Hall D

Systematic effects of fishing on global coral reef herbivore populations

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The most useful resilience and restoration strategies for threatened and degraded coral reefs must focus on realistic management targets. Herbivores are known to maintain and perhaps rebuild reef resilience. However, little is known about if and how fishing alters herbivore biomass or community structure, making development of management targets difficult. We conducted a global synthesis of the variability in biomass of key coral reef herbivore feeding guilds between fished and unfished locations at regional and global scales. An exhaustive search of peer reviewed literature and data from scientific monitoring programs yielded a dataset of over 700 individual estimates of biomass from 107 locations worldwide. Mean herbivore biomass at unfished and fished sites was 46.2 and 16.1 g/m^2, respectively, independent of regional effects. There was significantly greater biomass of the largest bodied scraper/excavator feeding guild at unfished sites (25.51 g/m^2) than at fished sites (4.43 g/m^2), also independent of regional effects. Results suggest exploitation of coral reef fishes strongly impacts herbivore assemblage structure and biomass. Disproportionate loss of the scraper/excavator sub-guild likely results in the loss of taxa most important for maintaining low fleshy algal abundance and promoting crustose coralline algae and coral recruitment. Effective restoration strategies should not simply consider herbivores as a single group but also maintain feeding guilds in proper ratios. As herbivores play an important role in maintaining the balance between algal and coral cover, these results have significant implications for the development of management strategies to improve the resilience and restoration of the world's coral reefs.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1630, Hall D

Acoustic telemetry and network theory find herbivores display 'small-world' dynamics

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Organisms that actively move across the coral reef connecting various habitats and linking individual reefs (mobile links) are considered paramount in supporting the health and resilience of reef ecosystems. Although herbivorous fishes are frequently cited as examples of such mobile link organisms, we know very little of how mobile they actually are through space and time. Using an array of remote acoustic receivers we tracked the movements of three species of herbivore (*Chlorurus microrhinos*, *Scarus rivulatus* and *Siganus doliatus*) along a 3 km stretch of reef over a period of 10 months. Despite differences in their functional ecology and body size, all three species exhibited surprising similarity in their spatial ecology, with small home ranges (average 200 m stretch of reef) and high levels of site fidelity. In a novel application of social network theory we classify the movement patterns of individuals and find that the behaviour of most fishes approximates to the 'small-world' class of organisational network that have inherent structural vulnerability. Our results suggest that within the herbivorous reef fish community only a few individuals meet the criteria of being true mobile links and that the importance of these organisms lies not just in their role of providing connectivity between habitats, but in their ability to provide insurance against targeted attacks on the reef. We discuss the implications of this new approach to characterising the movement and functional impact of fishes in terms of its applicability to reef management.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1730, Hall D

How top-down control by predatory fishes and humans influence reefs

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Apex predators exert a strong top-down control on the entire coral reef ecosystem, yet they are the most vulnerable to exploitation and their loss can influence lower trophic groups, size structure of the fish assemblage, and the overall productivity of the ecosystem. Long-term data from the US Virgin Islands shows that large groupers were once common but have declined in abundance in recent decades with a concomitant increase in the number of smaller grouper species, likely due to

competitive release. Additionally, schools of mobile herbivores have decreased over time while small resident herbivores have increased, contributing to the overgrowth of these reefs by algae. Analogous increases in meso-carnivores and non-territorial herbivores were observed at fished atolls in the Northern Line Islands. In Hawaii, overfishing of both predators and prey has led to declines in total biomass along a gradient of human population. Ecosystem services such as sand production and control of macroalgae have been impacted by the removal of large herbivores. MPAs in Hawaii have rehabilitated these services but only larger protected areas conserved apex predators and intact fish assemblages. At the most isolated Northwestern Hawaiian Islands and at unfished atolls in the Northern Line Islands, parrotfishes on reefs with more predators changed sex at smaller sizes than reefs with fewer predators and increases in the relative proportions of smaller prey were generally consistent with increased cropping rates. Collectively these results point to the alteration of coral reefs by humans and the importance of predators in maintaining ecosystem function.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1145, Hall D

Differential grazer effects influence algal composition and development in Kenya

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Herbivory is an important top-down force on coral reefs that mediates macroalgal abundance and provides resilience following disturbances. Understanding the roles of particular herbivore species or functional groups in driving community dynamics on coral reefs is becoming increasingly important, as ecosystems are affected by climate change and overfishing and their resilience eroded. Herbivore composition and diversity could be especially critical on east African coral reefs where herbivorous fishes and sea urchins co-occur, and fish are heavily exploited and display family-specific and functional group recovery patterns. Some herbivorous fish are highly sensitive to fishing while other species are not and yet they each play different functional roles. These factors may lead to a poor recovery of herbivores in young fisheries closures. The succession change of sea urchins, grazers, and browsers could greatly influence the recovery, and the potential for either exiting or entering ecological cusps that can retard recovery and reduce ecosystem services. We tested this hypothesis using herbivory assays, and experimental coral plates and exclusion cages at protected areas of variable age and fished sites, to determine the differential effects of grazing functional groups on successional changes in algae. Preliminary results indicate there are periods of lost grazing intensity and type of grazing on different functional groups of algae due to differential responses of the functional groups to closure from fishing. These results will increase our understanding of how the transition and recovery of herbivorous fishes may influence phase shifts in benthic composition.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1215, Hall D

Herbivory and sea urchin predation on Ningaloo Reef, Western Australia

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Global degradation of coral reefs has left very few, if any, marine ecosystems without impact from human activity. Nevertheless, Ningaloo Reef in Western Australia is one coral reef ecosystem which shows signs of low levels of anthropogenic disturbances. This study investigated two common global bio-indicators for coral reef decline, macroalgae and sea urchin densities, and the presence of two of the functional groups that can regulate macroalgal and sea urchin abundance, herbivores and sea urchin predators. Surprisingly, both an abundant sea urchins population on the exposed slope and extensive macroalgal communities in the protected lagoon were detected. Significant variation in the densities of the four functional groups of herbivorous fish was evident. Crucially, only two species of excavating herbivores were present within the Marine Park, pointing to low levels of functional redundancy. Likewise, urchin predators on Ningaloo Reef are markedly different from elsewhere. Labrids, not balistids, appear to be the primary predators on adult sea urchins on Ningaloo Reef. However, strong habitat variation in the sea urchin population on Ningaloo Reef appears not to be a result of a lack of predators. Hence, we suggest that the high abundance of sea urchins on the slope and the well established macroalgal lagoon found on Ningaloo Reef may be the natural condition in this unusual system, and that these

two factors are not driven by anthropogenically induced low predation pressure.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1015, Hall D

Reef fish feeding impact on benthos remarkably varies with latitude

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Ecological theory predicts more biotic interactions in tropical systems than in colder regions. Such a pattern is expected to be reflected in reef fishes' feeding rates on benthos along a latitudinal gradient, with respect to number of bites and feeding interactions. For instance, the relative importance of herbivorous fishes is known to decrease towards subtropical reefs. We tested these hypotheses using remote video assays comparing three reef sites along the Brazilian coast: Abrolhos (NE; 17°58´S; tropical), Arraial do Cabo (SE; 22°58'S; subtropical) and Santa Catarina (S; 27°17'S; subtropical), with haphazardly selected replicated 2 sq.m reef areas recorded for 10 min. Total bite rate and feeding impact (mass standardized bite impact) per unit of area and time significantly varied among these sites, being higher at Abrolhos than at Santa Catarina. Arraial do Cabo presented intermediate values, suggesting the potential effect of temperature on reef fish physiology driving latitudinal gradients of both fish abundance and feeding impact on benthos. Acanthurids and scarids were the main families responsible for the feeding impact in tropical reefs, with substantial contributions from large bodied *Scarus* species. At Arraial do Cabo, despite high acanthurid feeding impact, the relative importance of *Scarus* species shifts to *Sparisoma* species, with an increased contribution of mobile invertebrate feeders. In the southernmost Brazilian reefs (Santa Catarina), herbivore contribution strongly decreases, while omnivores emerge as major players. This shift in total bite rates, feeding impact and composition of reef fish feeding on benthos increases the generality and importance of latitudinal gradients affecting ecosystem functioning.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1245, Hall D

Stop motion dynamics: inferring reef fish functional roles across ecosystem states

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The range of ecosystem states apparent on coral reefs result from a dynamic interplay of fish, corals, macroalgae and invertebrates. These interactions are mediated primarily by fish, in functional roles that become more or less important for reef function as reef states progress from healthy through degraded. But coral reef ecosystem dynamics are only partially observed, via snapshot data collected intermittently through space and time. So how then can we understand the dynamic behaviour of coral reefs from static observations? By examining a wide range of coral reef observations, critical thresholds in coral reef states across gradients of reef fish biomass and abundance become apparent. In combination, snapshots of coral reef states can provide important insights about the changing role of reef fish across varying ecosystem states.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1230, Hall D

Observing fish behaviour from space

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Coral reefs worldwide are threatened from many sources. Many are also large, remote, and difficult to monitor, limiting our ability to detect changes in reef health. It is well established that harvesting of predatory fishes has major impacts on other reef species. This research scales up from what is known about how both fishing and marine reserves indirectly affect herbivore behaviour over small scales, by quantifying how these interactions can collectively shape larger reef landscapes. On patch reefs isolated from one another by sand or other open substrate, herbivores concentrate their grazing in 'halos' around their reef refugia, the likely result of antipredator behaviour, creating seaweed-free zones. However, when predators are removed, for example by fishing, seaweed grows more uniformly over the reef floor. Freely-available satellite imagery of the entire earth's surface now allows examination of landscape features in even the most remote areas. I will present results demonstrating that grazing halos can be detected with this satellite

imagery, and that they relate to the levels of seaweed cover and herbivory surrounding patch reefs. The next step is to examine the presence and scale of grazing halos inside versus outside of marine reserves over a latitudinal gradient to determine if and how grazing halos may be used as a means of indirectly assessing aspects of reef health, such as recovery of depleted predator populations. By integrating remote sensing technology with behavioural ecological theory, this research may ultimately lead to the development of a low-cost, global-scale tool for reef managers worldwide.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1500, Hall D

The ecological role of grazing surgeonfish on Heron Island reef

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Herbivorous fish reduce growth of algal communities that compete with corals for space. Therefore, herbivory is widely acknowledged as a key ecological process that structures benthic communities and is important for the resilience of coral reefs. Investigating the different ecological roles of key herbivorous fish species is necessary for our understanding of reef resilience and targeted management plans. The family Acanthuridae (surgeonfish, unicornfish and tangs) are widespread and abundant members of most reef fish assemblages. The majority of acanthurid species are herbivores, and many species are heavily exploited in coral reef fisheries and the aquarium trade throughout the Indo-Pacific. Despite the prevalence of acanthurids on most coral reefs, little is known of their ecological roles as herbivores. Our research combines data from fish and benthic surveys, feeding observations, and manipulative field and aquaria experiments to quantify the extent of acanthurid grazing, and identify the roles of key species. Through aquaria experiments, we show that a common acanthurid grazer and detritivore both prefer sparse over dense turfs, and that the detritivore has the capability to remove turf algae in significant quantities, potentially functioning as an important grazer in reef ecosystems. By combining this information with acanthurid grazer biomass, grazing intensity, and turf algal productivity estimates, we present the ecological role of key acanthurid grazers and their impact on turf algal dynamics on Heron Island reef. This data fills knowledge gaps in acanthurid grazer feeding ecology, and provides information to aid management efforts of acanthurids in areas where they are heavily exploited.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1130, Hall D

Macroalgal removal and feeding selectivity of fishes on subtropical reefs

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Herbivorous fishes compose a keystone group in reefal environments, by affecting macroalgae distribution at different scales. In coral reef systems, numerous researchers have managed to determine the role of different fish species, and to quantify their impact on macroalgae assemblages. On the other hand, little attention has been given to this group on rocky subtropical reefs, generating a lack of knowledge in terms of importance of herbivorous fishes, in these systems. Remote video multiple choice feeding assays were performed with the purpose of determining the selectivity patterns of reef fishes towards the ten most abundant macroalgae species at the region. After 1.5 h of exposure, the most consumed macroalga was *Spyridia* with 75% of mass removed, followed by *Amphiroa* and *Colpomenia*. In contrast, *Laurencia* had only 7%, and *Plocamium* 10% of biomass removed. From the twelve fish species observed feeding, 73.5% of the standardized bites were taken by only two species: *Sparisoma tuiupiranga* (38.2%) and *Sparisoma axillare* (35.3%). The presence of secondary metabolites, as well as nutrient content of macroalgae, could be driving the selectivity patterns of herbivorous fishes. While the role and importance of macroalgae at these sites are largely overlooked, compared to coral reefs, herbivores may exert an important function in these systems. For example, in the study area *Spyridia* seems to be related to sewage discharge and was the most removed macroalgae by fishes. In a scenario of great nutrient input, herbivorous fishes may play a critical role in controlling the spread of this macroalgae.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1545, Hall D

Influence of habitat condition and competition on foraging behaviour of parrotfish

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Herbivores have been identified as critical for supporting the resilience of reefs within a coral

dominated state. However, research to date suggests that spatial changes in the behaviour of herbivorous species negates the use of simple measures of functional impact, such as herbivore biomass. Evaluation of the role of herbivorous species within the spatial patchiness of the landscape is therefore required. In this study we assess the influence of among site variation in habitat condition, predation and competition on the short term foraging mobility of two species of parrotfish, *Scarus niger* and *Scarus frenatus*, on mid-shelf reefs of the Great Barrier Reef. Foraging mobility was evaluated using three metrics: inter-foray group distance, area, and shape of short-term foraging range. The two strongest predictors of these various attributes of foraging behaviour were coral cover, followed by competitor abundance. For instance, inter-foray group distance decreased with increasing coral cover for both *S. niger* and *S. frenatus*. Furthermore, foraging ranges became more circular in shape with increasing coral cover for both species, and with decreasing competitor abundance for *S. niger*. This research provides a fundamental understanding of how habitat condition and competition among herbivores produce spatial variation in the scales at which herbivores interact with their environment, and perform functions essential for coral reef resilience. Critically, the study suggests that predicted changes in coral cover from increasing anthropogenic impacts are likely to alter the way reef fish herbivores provide key functions.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1515, Hall D

Reef fishes foraging associations: 'Nuclear-follower' behavior or an ephemeral interaction?

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The most common feeding association among coral reef fish involves nuclear and attendant species. The former causes a bottom disturbance attracting several species known as followers, which feed on items exposed by this activity. However, descriptions of novel events of nuclear-follower interactions do not take into account the complexity and importance implied by these associations. Herein we propose a novel classification for foraging associations, namely 'ephemeral foraging association' formerly grouped together as nuclear-follower behavior. For this classification, the interaction between the goldspotted eel *Myrichthys ocellatus* and other six reef fish species were taken as a case study. The present study was conducted between November 2009 and May 2010, in the Tamandaré Reef Complex, Pernambuco State, Northeastern Brazil. Observations were performed during daylight periods while snorkeling, with a total of 35 hours of direct observation. We recorded 18 occurrences for the 'ephemeral foraging interaction', while 42 individuals were observed. Interactions lasted from 30 seconds to 5 minutes and total lengths (TL) ranged from 4 to 10 cm. Most species were carnivores and territorial omnivores. Based on the way the associations were triggered, time spent on the association, cognitive reactions and territoriality of attendants, the recorded interactions may be separated into a different category among known attendant associations. The amount of cognitive response of coral reef fish species is a subject of discussion and should be addressed in further studies encompassing *in situ* or aquaria experiments to elucidate other mechanisms triggering the foraging associations.

13B The changing role of fishes in coral reef ecosystems
P121

Algal characteristics affect diet selection across an herbivorous fish community

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Despite similar taxonomy, herbivorous fishes can exhibit considerable variation in their diet selection. We conducted videotaped feeding assays with 22 species of algae and one seagrass on reefs around Moorea, French Polynesia to investigate species-specific feeding choices for the community of herbivorous fishes. For each species of algae we measured five characteristics associated with palatability; organic carbon content, nitrogen content, carbon:nitrogen ratio, number of secondary metabolites, and presence or absence of calcification. We used multidimensional scaling to examine complementarity and redundancy for the nine most common herbivorous fishes and multiple regression to investigate the influence of algal characteristics on diet selection. The browsing species *Siganus argenteus* and *Naso lituratus*, expressed relatively high redundancy in food choice, however feeding by *S. argenteus* displayed a positive relationship with organic carbon content while feeding by *N. lituratus* was best explained by increases in C:N ratios and nitrogen content. Similarly, three species of Acanthuridae (*N. unicornis*, *N. vlamingii* and

Zebrasoma scopas) displayed overlapping diets, but their selections for each algae were again best explained by different algal characteristics; either increases in organic carbon content or lack of calcification for the respective *Naso* species, or a combination of all factors except secondary metabolites for *Z. scopas*. Thus, even in fishes with apparently redundant diets, species-specific foraging decisions were often influenced by different algal characteristics, which may alleviate competition between seemingly redundant groups. This study represents one of the first assessments of how algal traits impact species-specific herbivore feeding preferences across the herbivore guild.

13B The changing role of fishes in coral reef ecosystems
P122

Biological traits predict movement patterns in coral reef fish

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Movement of adult coral reef fish within and between reefs is likely to influence the spatial structure of reef recovery and functioning, as well as determining the success of no-take areas for fisheries management. Although numerous studies measure the movement of one or several species, there has been no comprehensive comparison of a large number of species at a single location. We measure movement across 350 adult reef fish from 25 species and 10 families, enabling us to test the extent to which movement can be predicted by biological traits, including maximum body size, trophic group, morphology and shoaling behaviour. Movement was measured amongst 6 reefs in the Northern Farasan banks in the Red Sea, using acoustic telemetry. This included a high-resolution receiver array on 2 island reefs (circumferences of 3 km each) to capture within-reef movement; and a low-resolution array on an additional 4 reefs (between 800 m to 5 km apart), to capture between-reef movement. Movement was measured over a 6-month period. We use linear models to explore the relative effect of different traits on movement, revealing the extent to which movement can be predicted by biological traits. Such predictions would allow estimates of relative movement amongst species in other reef systems. Given the potential importance of key species and groups for reef functioning, incorporating estimates of relative movement of adult fish could significantly improve the design of spatial reef management plans.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1715, Hall D

Spatial ecology of the steephead parrotfish (*Chlorurus microrhinos*)

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The functional roles of reef fish species are important in maintaining resilience on coral reefs worldwide. However, the spatial scales over which individual fish apply their functional role remains almost entirely unknown. The parrotfish, *Chlorurus microrhinos*, is particularly important on the Great Barrier Reef (GBR), and has been documented to contribute significantly to the ecosystem processes of bioerosion and algal removal on inshore reefs. However, as is the case for all parrotfishes on the GBR, very little in known about its spatial ecology. The home range and feeding areas of *C. microrhinos* on Orpheus Island, GBR, were quantified using active acoustic telemetry. The average home range of *C. microrhinos* was 7,830 m^2 ± 940 (± SE). Core areas of activity (50% kernel utilization distributions) were relatively small, encompassing approximately 22% of an individual's home range (1,690 m^2 ± 220). Feeding intensities were not homogenous throughout the home range, with core areas possessing two times more feeding scars than non-core areas. These core areas are therefore exposed to increased bioerosion and algal removal from *C. microrhinos*. Core areas were found to be associated with areas of reef with greater topographic complexity and shorter distances to shelter, possibly indicating a decreased predation risk in these areas. The ecosystem impact of individual *C. microrhinos*, on Orpheus Island, appears to be restricted with little evidence for roving behaviours in the species. The loss of an individual from the reef may therefore result in a localized reduction of key ecosystem processes.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1700, Hall D

The indirect effects of predation on coral reef fishes

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Efforts to understand the effects of fisheries exploitation on marine communities are widespread. Most notable results include reductions in large-bodied species and subsequent alteration of species composition, standing stock, and size-structure of fish assemblages. Although these efforts provide valuable insights into the direct effects of extraction, few efforts have been made to describe the indirect effects of predator removal on non-targeted species. We explore the indirect effects of predation on fish assemblages by comparing life-history characteristics and body condition factors of fishes along a gradient of predator biomass. This was accomplished by performing targeted collections of a subset of the most abundant reef fishes from six islands in the central Pacific that span a gradient of predatory fish biomass. Using size-at-age estimates and body condition factors we found that responses are linked to predator abundance and that patterns vary across trophic levels. At islands where predators are abundant, prey species tend to show increased growth rates, reduced longevity, and smaller size relative to islands with fewer predators. Further, indices of condition such as length-specific body mass and liver mass of prey species relate negatively to changes in predator density. These findings suggest that predators can indirectly affect the prey assemblage even when signs of a prey release or trophic cascade are not evident. Focused efforts to identify the indirect effects of predators on the life history and condition of prey species are imperative for understanding the dynamics of complex systems, and for the development of effective management and recovery plans.

13B The changing role of fishes in coral reef ecosystems
Monday 9 July, 1745, Hall D

13C Ecological effects of habitat degradation

Specializing on vulnerable habitat: *Acropora* selectivity among coral-associated damselfishes

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Coral reef habitats are increasingly being degraded and destroyed by a range of disturbances, most notably climate-induced coral bleaching. Habitat specialists, particularly those associated with susceptible coral species, are clearly among the most vulnerable to population decline or extinction. However, the degree of specialization on coral microhabitats is still unclear for one of the most ubiquitous, abundant and well-studied of coral reef fish families - the damselfishes (Pomacentridae). Using high taxonomic resolution surveys of microhabitat use and availability, this study provides the first species-level description of patterns of *Acropora* selectivity among recruits of 10 damselfish species. In addition, surveys of the bleaching susceptibility of 16 branching coral species reveal which preferred recruitment microhabitats are at highest risk of decline as a result of chronic coral bleaching. Four damselfish species are identified as highly vulnerable due to their restricted use of only branching hard corals as recruitment habitat and their specialized associations with only 2-4 coral species. The bleaching surveys revealed that 5 species of *Acropora* are highly susceptible to bleaching, with more than 50% of colonies either severely bleached or dead. These highly susceptible corals include two of the preferred microhabitats of the *Acropora* specialist *C. parasema* and represent one-third of its total recruitment microhabitat. In contrast, highly susceptible corals were never used by another specialist, *Pomacentrus moluccensis*, suggesting that this species faces lower risk of bleaching-induced habitat loss. Linking information on habitat preferences with the susceptibility of those habitats to degradation can significantly improve risk-assessment for coral-associated reef fishes.

13C Ecological effects of habitat degradation
Thursday 12 July, 1115, Hall A

Long term demographics of coral-reef damselfishes and associated coral habitat

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Surveys of patch reefs in and around One Tree Island lagoon, southern GBR have been conducted since 1993. The dynamics of coral cover at 9 sites has been monitored annually, and associated bleaching events have been recorded. In parallel, censuses of coral-reef damselfishes have been undertaken, and links between ongoing changes in coral habitat and fish populations established. Coral bleaching events in 1998, 2001, 2004 etc. have caused dramatic coral losses within One Tree lagoon at some sites but not others. Coral species responses to bleaching conditions vary, and both coral cover and species abundances have changed dramatically over the 18 years of monitoring. Damselfish recruitment and adult densities have, for some species, closely tracked coral cover and responded to bleaching events, however, some species appear more resilient to coral cover fluctuations, while other species recruit and adult numbers have either

declined, increased or fluctuated over broader temporal cycles.

13C Ecological effects of habitat degradation
Thursday 12 July, 1630, Hall A

Interacting effects of habitat degradation and competition on coral-reef damselfishes

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Coral reef habitats provide critical resources to reef fish inhabitants, including nutrition, shelter, breeding and recruitment. Although habitat degradation may exacerbate competition for these critical resources, the relationship between habitat quality and competitive interactions is poorly understood. In this study we used a manipulative patch reef experiment to test the effects of live coral degradation on competition between two planktivorous, coral-dwelling damselfishes, *Chrysiptera parasema* and *Dascyllus melanurus*. Patch reefs were constructed with either healthy (100% live) or degraded (10% live) bottlebrush *Acropora*, stocked with varying densities of the two fish species, and monitored over two months. There was a significant interaction between habitat degradation and competition for *C. parasema*. On healthy reefs, the presence of competitor *D. melanurus* increased mortality of *C. parasema* by 50%, whereas on degraded reefs mortality was uniformly high regardless of *D. melanurus* presence. Additionally, *C. parasema* mortality increased with conspecific density on healthy reefs, but not on degraded reefs. In contrast, there was no interaction between habitat degradation and competition for *D. melanurus* and mortality was not influenced by the presence of *C. parasema* in either habitat treatment. Furthermore, behavioural observations revealed that *D. melanurus* per capita aggressive interactions increased with density on degraded habitat, but not on healthy habitat. The study has demonstrated that quality of habitat can change the behaviour of reef fishes and the nature of their competitive interactions, with a decline in reef fish numbers as a direct consequence.

13C Ecological effects of habitat degradation
Thursday 12 July, 1145, Hall A

Future trajectories of architectural complexity and biodiversity on Caribbean reefs

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The architecture of coral reef habitats is mainly generated by the growth and calcification of reef-building corals, yet little is known on the effects of coral disturbances on the quality of reef habitats. As the disturbance regime of coral reefs is expected to rise with climate change, there is increasing concern about the degradation of architectural complexity of Caribbean reefs and the potential impacts on reef-associated organisms. Models of coral reef ecosystems were developed to predict future changes in the structure of reef habitats and the response of the diversity of reef communities. The models describe the dynamics of corals competing for space with macroalgae under the control of multiple disturbances (such as hurricanes, coral bleaching and acidification), in different reef environments of the Caribbean. Coral-algal dynamics are simulated over decades with various disturbance regimes following climate change scenarios. At each time step, the reef architectural complexity is quantified by the contribution of coral colonies to the actual surface area of the reef bottom, thus generating an index of reef rugosity which varies over time. Empirical relationships linking reef rugosity and the diversity of fish and conspicuous invertebrates are used to predict temporal changes in reef biodiversity in response to habitat structure. Simulations show how climate change may cause further declines in the architectural complexity of Caribbean reefs, thus affecting reef biodiversity and the persistence of related ecosystem services.

13C Ecological effects of habitat degradation
Thursday 12 July, 1645, Hall A

Specialisation by a corallivorous reef fish: consequences on changing reefs

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Limited ecological versatility leaves specialised species particularly vulnerable to habitat disturbances. Fishes which feed on coral represent some of the most specialised organisms on coral reefs. Recent studies have shown that these fishes can be highly selective in their choice of coral prey. This limited dietary scope implies that these species will be directly affected by disturbance events which alter coral community composition. The harlequin filefish, *Oxymonacanthus longirostris*, feeds almost exclusively on corals from the genus *Acropora*. Prey preferences were established through field observations and aquarium choice

experiments and indicated fish are highly selective between individual *Acropora* species. The relationship between corallivore prey choice and fitness maximisation is poorly understood. This relationship was examined by comparing condition and reproductive output of *O. longirostris* breeding pairs maintained on exclusive diets of a preferred vs. non preferred *Acropora* species. Body condition of fish maintained on preferred coral was significantly better than those fed non-preferred prey. This directly affected reproductive output as pairs fed non-preferred coral did not breed. This suggests that the quality of coral as a dietary resource can vary markedly between species and patterns of prey selectivity reflect these differences. Increasing anthropogenic disturbance is predicted to decrease coral cover and diversity on reefs. The striking differences in fitness observed suggests that, while fish may have the ability to consume a variety of corals, loss of key individual species will have direct negative effects for associated corallivore populations.

13C Ecological effects of habitat degradation
Thursday 12 July, 1745, Hall A

Responses of reef fish communities to large-scale habitat perturbations

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Our ability to predict how communities of coral reef fishes will change in response to habitat alteration depends strongly on understanding the functional relationships of component species with live coral and reef structure, together with how these aspects are shaped by wave exposure and various perturbations. The forereefs of Moorea, French Polynesia, have experienced two ecologically significant pulse perturbations since 2007; a wide-scale COTS outbreak that severely reduced the cover of live coral around the island, followed by a cyclone that reduced the structural complexity of the forereef along Moorea's north shore by removing much of the dead coral. Prior to these disturbances, the fish assemblages on the forereef demonstrated consistent spatial differences in species composition that were related to differences in the wave energy incident to different localities around the island. Following the disturbances, fish communities at these localities responded in a consistent fashion independent of the initial species composition. Fish species strongly associated with living corals declined island-wide, and assemblages found along the usually less wave impacted north shore became more similar to those found along the more wave impacted southwestern shore. Surprisingly, fish species richness remained virtually unchanged and the total biomass of fishes increased. This counter-intuitive response resulted from the replacement of small, coral dependent species by larger-bodied, coral rubble associated species and an island-wide increase in the abundance and biomass of herbivores.

13C Ecological effects of habitat degradation
Thursday 12 July, 1530, Hall A

The Goliath Grouper (*Epinephelus itajara*) escape from fishing in Santa Catarina, southern Brazil

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The Goliath grouper occurs along the Atlantic west coast, from Florida to Santa Catarina, and in the west of Africa; inhabiting coral and artificial reefs, rocky shores and mangroves. Its slow growth and reproductive rates, and its group spawning behavior, make it particularly vulnerable to overfishing. In Brazil, the decline of populations, the loss of mangrove habitat and lack of data on the species, have resulted in maintenance of the regulation that has prohibited the harvesting of Goliath groupers since 2002. Globally, relatively little work has been conducted on spawning aggregations and few sites have been the specific focus of monitoring and management activities. In Brazil, the “Meros do Brasil” project has obtained information from old fishermen about specific historical locations of Goliath grouper aggregations in Santa Catarina state. Since 2007, diving researchers of the project have been monitoring the sites “Ilha dos Lobos” Island, Tamboretes and Graças archipelagos, and Monobóia artificial reef, which were indicated by the fishermen as having a high frequency and number of *E. itajara* aggregations. Over four years of research, only the Monobóia, an artificial structure used by petroleum ships to unload, which is protected by Brazilian Navy and is almost free of fishing, had a Goliath grouper aggregation, with more than 45 individuals. At the island sites, only four specimens were observed together at the same time in all the years of in-water observation, a

very different result from the thirty individuals related by the old fishermen. This evidence indicates a refuge for the fish at Monobóia, where they do not suffer from fishing.

13C Ecological effects of habitat degradation
P123

Modeling the impact of decreasing coral reef complexity on fish distributions

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Coral reef ecosystems exhibit complex vertical and horizontal structural heterogeneity at a range of spatial scales. This heterogeneity plays an important ecological role in influencing the distribution, abundance and behavior of marine organisms. Shallow-water coral reefs, however, are proving vulnerable to rapid environmental change. Topographic complexity of Caribbean coral reefs is reported to have declined by 50% during the last 40 years. This 'flattening' of seafloor structure is likely to continue due to stress from land-based sources of pollution, hurricanes and climate change that combine to degrade coral reefs. Loss of topographic complexity will have major consequences for fish communities because suitable habitat disappears or is impaired with suboptimal ecological function. Ecological impacts will need to be anticipated to ensure that management actions are well targeted and that expectations for recovery after protection are ecologically realistic. To address this crucial knowledge gap, we modeled the distribution of several fish species under a range of reef flattening scenarios for a shallow-water coral reef ecosystem in southwestern Puerto Rico. Preliminary results show that the area of suitable habitat for several common fish species contracted and then fragmented across the seascape. We highlight species-specific vulnerability to loss of structural complexity. Our forecasting techniques provide resource managers with spatially-explicit information that can help anticipate future changes to essential fish habitat, fisheries catch, marine protected area performance, biodiversity patterns and population viability of endangered species associated with coral reef ecosystems.

13C Ecological effects of habitat degradation
Thursday 12 July, 1545, Hall A

Cardiorespiratory physiology and energetics of reef fishes

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Reef fishes are experiencing a changing environment. Water temperatures are progressively increasing in many locations around the world, and the oceans are becoming more acidic. While much research focuses on the role of coral health and reef structure in determining the resilience of reef fishes to climate change, little is known of the direct impacts of temperature and acidification on fish populations. Indeed, it is possible that some fish species will prove less resilient to climate change than the corals that surround them. This presentation outlines how climate change directly influences the physiology of reef fishes and thus their capacity to function and survive. Using large (coral trout) and small (pomacentrids) species as models, this presentation highlights how a fundamental process - oxygen transport from the environment to the tissues of the body - may underlie interspecific differences in resilience to environmental change.

13C Ecological effects of habitat degradation
Friday 13 July, 1000, Hall A

Recovery of fish communities following habitat degradation

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Corals reefs are subjected to multiple disturbances that impact levels of coral cover and the complexity of the reef matrix, and in turn influence the structure of associated fish communities. With disturbances predicted to increase, an understanding of how impacts, through the change in substrate health, will influence the recruitment of many fishes, is essential for understanding the recovery of reefs following biological and physical disturbances. While studies have revealed that live coral and habitat complexity is important for many recruiting fishes, there is a lack of evidence stating how a combination of changes will impact the recruitment of fishes. By using manipulated man-made patch reefs consisting of 6 different habitat treatments; 3 levels of live coral cover (high, medium, low) crossed with 2 levels of habitat complexity (high, low), we were able to investigate the independent and combined effect of varying levels of live coral cover and structural complexity on the recruitment and recovery of fish communities. Our results show that there were little differences in abundance and species richness between the 6 habitat treatments. Although, we found using multivariate techniques, significant

differences in the associated fish communities between treatments driven by coral-dwelling fishes, which depend on high coral cover, high complex reefs. These results show that although fishes will still recruit to degraded reefs following disturbances, these fish communities are significantly different and dominated by rubble associated species. Furthermore, we found that live coral cover is important for the recruitment of some non-coral depended species.

13C Ecological effects of habitat degradation
Thursday 12 July, 0945, Hall A

Sedimentation impacts coral use by juvenile parrotfishes, west Hawaii Island

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Some major anthropogenic stressors have episodic impacts that occur at infrequent, unpredictable intervals; their effects are difficult to evaluate in a timely manner. Substituting space-for-time along an environmental gradient that aliases a predicted temporal response to habitat restoration can avoid the delays of decades-long monitoring when evaluating restoration responses. We here describe the first 2 year results of a short-term study that combines field experiments and descriptive surveys of a fringing reef at Pelekane Bay, west Hawaii, along a sedimentation gradient from an intermittent stream that episodically discharges from the Kohala Watershed. This degraded watershed is now being restored by grazer exclusion, habitat engineering, and replanting of native flora. Arrays of settling plates, marked branches of endemic finger coral *Porites compressa*, and sediment traps, together with surveys of benthic composition, densities of recruits of economically important parrotfishes, and the relative use of corals by fish recruits, were evaluated during summer-fall periods of 2010 and 2011. All of the coral metrics and the relative use of corals by recruit fishes generally increased as expected with increasing distance from the point of stream discharge. Overlaying our results on habitat distributions (being mapped by a separate study) is allowing a cost-benefit evaluation of potential watershed reclamation on reef resources prior to documentation of long-term restoration effects that might occur decades in the future.

13C Ecological effects of habitat degradation
Thursday 12 July, 1730, Hall A

Coping with climate change across generations

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The capacity for organisms to acclimate and adapt to global warming is of vast importance for establishing the likelihood of persistence of current populations. While the short-term effects of future predicted temperatures on species is well established, an understanding of how acclimation over generations may allow animals to cope with increasing environmental temperature is currently a critical knowledge gap. To determine the potential for temperature sensitive attributes to improve with development and persistence of multiple generations in future predicted ocean conditions, 3 generations of the common damselfish *Acanthochromis polyacanthus* were maintained under future ocean temperatures. Temperature treatments were the current-day average and temperatures that could become the average for this region over the next 50-100 years (+1.5℃ and +3.0℃ to current-day). Key reproductive, morphological and physiological attributes were compared between temperature treatments within a generation as well as between generations, to identify how temperature sensitive traits vary or improve with time. Findings indicate acclimation of many traits are possible within a few generations, suggesting that future populations of tropical reef fish may not be as severely affected by temperature increases as short-term experiments to current-day populations indicate.

13C Ecological effects of habitat degradation
Thursday 12 July, 1500, Hall A

Disturbances on the Great Barrier Reef: how do reductions in habitat complexity affect reef fishes?

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Coral reefs are subject to a range of disturbances, some just kill hard corals leaving skeletons standing (e.g. *Acanthaster planci* infestations, coral bleaching and disease), whilst others kill coral and reduce habitat complexity (e.g. storms). Numerous studies point to varied responses from fish communities, however due to the random nature of disturbance events, studies of effects on reef fishes tend to be of an opportunistic nature, generally sampling around one event. Here we use a long term dataset

encompassing much of the Great Barrier Reef (GBR) to analyse the effects of more than 70 disturbance events on reef fish communities. In particular, we compare disturbances where only live coral was reduced with disturbances that reduce both live coral and habitat structure. Numerous disturbances have impacted the GBR from 1995 to 2011, with *A. planci* and storms accounting for the greatest proportion of lost coral cover. Disturbances that reduced habitat complexity had the greatest effects on reef fish communities, although there was considerable variation in the response among fish taxa. Species that were closely associated with hard corals, such as obligate corallivores and species that live in coral colonies or settle in living coral were most adversely affected, however the response of many species varied among different types of disturbance. Our results suggest that there are few generalisations in predicting how disturbances will affect reef fish communities as effects depend on the type and magnitude of the disturbance, and the type, composition and geographic position of the reef community.

13C Ecological effects of habitat degradation
Thursday 12 July, 1130, Hall A

Beyond coral species: specific coral preferences of reef fishes

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Associations of a few reef fish guilds with particular coral genera and growth forms have long been recognised. Recently however, similarly strong associations have been shown for a larger proportion of reef fish assemblages, occurring across multiple families, trophic groups and life-stages. While the importance of live coral cover to reef fish assemblages is not underestimated, the degree of specificity by fish towards particular types of corals has been. Here we review coral selectivity by different groups of coral reef fish. Strong habitat associations and active preferences by many reef fish guilds, extend towards specific genera and species of corals, growth forms, colony sizes, the substrata underlying coral colonies, interstitial dimensions and even positions within coral colonies. Many fish species depend on more than just live tissue and availability of branching corals. The frequency of fine scale associations reviewed here suggests subtle changes in coral distributions, such as damage to larger corals or favoured colonies, could alter whole fish assemblages relatively quickly.

13C Ecological effects of habitat degradation
Thursday 12 July, 1715, Hall A

Suppression of herbivory by macroalgal density

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Consumers select habitats to maximise their energy intake while minimising their risk of predation. The factors influencing this trade-off between bottom-up and top-down forces are intrinsically linked to the physical structure of the habitat, with relatively small changes in habitat configuration often leading to a marked shift in habitat use. On coral reefs, the combined effects of climate change and anthropogenic stressors are fundamentally changing the physical structure and functioning of reef communities, with some reefs undergoing shifts from coral- to macroalgal-dominance. Although the physical structure provided by corals is widely regarded as a key feature that moderates predation risk, thereby facilitating herbivore activity, the influence of the physical structure of macroalgal stands is largely unknown. Using transplanted *Sargassum*, the largest coral reef macroalga, we created habitat patches that varied in macroalgal density (0.25-6.23 $kg.m^{-2}$) and physical structure. Feeding by herbivorous fishes was quantified on both the algal turf covered benthic substratum (i.e., grazing) and the *Sargassum* (i.e., browsing) using remote underwater video cameras. We found that both grazing and browsing fishes avoided patches with high macroalgal biomass, preferring relatively open habitat patches with low cover and biomass of macroalgae. This avoidance of higher macroalgal density patches appears to reflect a general aversion to a habitat in which predators are likely to be found. Given the importance of herbivorous fishes in structuring benthic communities these habitat preferences are likely to have positive feedbacks leading to the growth and stability of macroalgal stands on coral reefs.

13C Ecological effects of habitat degradation
Thursday 12 July, 0930, Hall A

Depth-related patterns in the distribution, habitat use and specialisation of coral reef fishes

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Organisms exhibit distinctive patterns of distribution in response to a range of environmental gradients. Depth is often a major

source of variation in the diversity and species composition of coral reef fish communities, but the underlying factors influencing these patterns are poorly understood. Most shallow-water studies (<10 m) have stressed the importance of coral habitat in determining reef fish community structure. However, given that coral cover often diminishes with depth, we hypothesized that fish would be less reliant or specialized on coral in deeper water and have broader depth-distributions. To test this, we examined the depth-related patterns in the distribution, habitat use and specialisation in coral reef fishes of the families Labridae and Pomacentridae on mid-shelf reefs of the GBR. Depth explained considerable variation in these reef fish assemblages and their associated habitat. Depth ranges were greatest for species with an intermediate mean depth of occurrence, and depth ranges became more restricted towards the extremes of the depth gradient. In contrast to expectations, niche breadth decreased overall with increasing mean depth of occurrence, suggesting that deeper species were more specialised, including strong associations with coral. Hence, deeper water fishes may be just as susceptible to coral loss as their shallow water counterparts.

13C Ecological effects of habitat degradation
P124

The effect of coral morphology on shelter selection by reef fishes

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While the loss of structural complexity causes declines in coral reef fish diversity, the processes leading to this decline are largely unexplained. To explore the role of coral morphology in providing shelter for fishes, tabular, branching and massive corals were filmed with video cameras and their usage by large reef fishes compared. Tabular corals were utilised more than the other two morphologies, with at least twice the abundance, biomass and residence times of large fishes. The preference of coral reef fishes for specific structural traits of tabular corals was also examined using artificial structural units. This experimental component showed that large reef fishes preferred dark rather than translucent canopies. It appears that large fishes cue to tabular corals because of the shade and concealment provided. It is suggested that a loss of tabular corals as a result of climate change would have significant ecological impacts for the coral reef fishes that use these structures for shelter.

13C Ecological effects of habitat degradation
Thursday 12 July, 1750, Hall A

Relative importance of various habitat characteristics in determining the structure of reef fish communities

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The structure of coral reef habitat has a pronounced influence on the diversity, composition and abundance of reef-associated fishes. However, the particular features of the habitat that are most critical are not always known. Coral habitats can vary in many characteristics, notably live coral cover, topographic complexity and coral diversity, but the relative effects of these habitat characteristics are often not distinguished. Here, we investigate the strength of the relationships between these habitat features and local fish diversity, abundance and community structure in the lagoon of Lizard Island, Great Barrier Reef. In a spatial comparison using sixty-six 2m² quadrats, fish species richness, total abundance and community structure were examined in relation to a wide range of habitat variables, including topographic complexity, habitat diversity, coral diversity, coral species richness, hard coral cover, branching coral cover and the cover of corymbose corals. Fish species richness and total abundance were strongly associated with coral species richness and cover, but only weakly associated with topographic complexity. Regression Tree analysis showed that coral species richness accounted for most of the variation in fish species richness (63.6%), while hard coral cover explained more variation in total fish abundance (17.4%) than any other variable. In contrast, topographic complexity accounted for little spatial variation in reef fish assemblages. In degrading coral reef environments, the potential effects of loss of coral cover and topographic complexity are often emphasized, but these findings suggest that reduced coral biodiversity may ultimately have an equal, or greater, impact on reef-associated fish communities.

13C Ecological effects of habitat degradation
Thursday 12 July, 1200, Hall A

High gene flow reduces vulnerability to habitat degradation for a specialised coral-feeding butterflyfish

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The vulnerability of ecologically specialised species to environmental fluctuations has been well documented. However, population genetic structure can influence vulnerability to environmental change and recent studies have indicated that specialised species may have lower genetic diversity and greater population structuring compared to their generalist counterparts. To examine whether there were differences in population genetic structure between a dietary specialist (*Chaetodon trifascialis*) and a dietary generalist (*C. lunulatus*) we compared the demographic history and levels of gene flow of these two related coral-feeding butterflyfishes. Using allele frequencies of >11 microsatellite loci and >350 bases of mitochondrial control region sequence, our analyses of *C. trifascialis* and *C. lunulatus* from five locations across the Pacific revealed contrasting demographic histories and levels of genetic structure. Heterozygosity excess tests, neutrality tests and mismatch distributions were all highly significant in the dietary specialist *C. trifascialis*, suggesting genetic bottlenecks have occurred in all locations. In contrast, we found little evidence of genetic bottlenecks for the dietary generalist *C. lunulatus*. High gene flow and low genetic structuring was detected among locations for *C. trifascialis*. Contrary to expectations, a greater level of genetic structuring between locations was detected for *C. lunulatus*. These results suggest that dietary specialisation may affect demographic history through reductions in population size following resource declines, without affecting population structure through reductions in gene flow. Although *C. trifascialis* is highly vulnerable to climate-induced coral loss, the high gene flow detected here suggests populations will be able to recover from local declines through the migration of individuals.

13C Ecological effects of habitat degradation
Thursday 12 July, 1015, Hall A

Degraded coral disrupt innate antipredator responses of fish

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Decreases in ocean pH, along with increases in water temperature and the prevalence of severe storms, have lead to bleaching and death of hard corals that underpin coral reef ecosystems, and these effects are predicted to worsen. As coral reefs degrade from live, healthy coral to rubble, fish diversity and abundance declines. This is in part due to fundamental changes in the interaction between predators and their prey, which will have repercussions for food webs and energy cycles. While broad predictions can be made, the mechanisms underlying changes in these processes remain poorly understood. We undertook experiments in the laboratory and field to determine how the predator risk assessment abilities of juvenile coral reef fish prey (*Pomacentrus amboinensis*) were affected by three different coral reef habitats, which represent a cline from healthy to degraded coral. We found that the environmental context in which the prey detected predation cues strongly influenced the balance of senses used by prey to assess risk. In dead coral habitats fish did not respond to alarm cues that are known to produce innate antipredator responses. This lack of response will increase the probability of being preyed upon. While olfactory and visual information concerning risk had an additive effect in the healthy coral habitat, this was not the case in a dead coral habitat. The mechanisms by which dead coral masks the response to alarm cues are unknown, but these effects will have dramatic repercussions for survival and recruitment in degraded habitats.

13C Ecological effects of habitat degradation
Thursday 12 July, 1030, Hall A

Habitat biodiversity as a determinant of fish community structure on coral reefs

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Increased habitat diversity is often predicted to promote the diversity of animal communities because a greater variety of habitats increases opportunities for resource specialisation and coexistence. Although positive correlations between the diversities of habitat and associated animals are often observed, the underlying mechanisms are only starting to emerge and none have been tested specifically in the marine environment. Scleractinian corals constitute the primary habitat-forming organisms on coral reefs and play an important role in structuring associated reef fish communities. Using the same field experiment in two localities differing in regional fish species composition, we tested the effects of coral species richness and composition on the diversity, abundance and structure of the local fish community. Richness of coral species overall positively affected fish species richness, but not total fish abundance. Certain coral species supported similar levels of fish diversity and abundance as the high coral richness

treatments, suggesting that particular coral species are disproportionately important in promoting high local fish diversity. Furthermore, different coral species supported very different fish communities, indicating that most reef fish distinguish habitat at the level of coral species. Fish communities colonising treatments of higher coral species richness represented a combination of those inhabiting the constituent coral species. These findings suggest that mechanisms underlying habitat-animal interaction in the terrestrial environment also apply to marine systems, and highlight the importance of coral diversity to local fish diversity. The loss of particular key coral species is likely to have a disproportionate impact on the biodiversity of associated fish communities.

13C Ecological effects of habitat degradation
Thursday 12 July, 1515, Hall A

Banggai Cardinalfish Ornamental Fishery: the importance of microhabitat

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In the marine realm restricted range endemic species are rare. One such species which has attracted much attention is the Banggai cardinalfish (*Pterapogon kauderni*, Koumans 1933), often referred to as BCF, a coral reef associated fish endemic to shallow waters (0-5 m) around the Banggai Archipelago, Indonesia. Traded as a marine ornamental, the IUCN Red-List places *P. kauderni* in the 'Endangered' category, with overexploitation and habitat degradation as the major threats. After the (unsuccessful) proposal for listing under CITES Appendix II in 2007, a national action plan (BCF-AP) was developed and BCF conservation included in the Indonesian Coral Triangle Initiative National Plan of Action. The fishery is now one of the major driving forces for conservation of both the BCF and its habitat, which includes some of the most valuable and vulnerable reefs in the archipelago. Biophysical and socio-economic monitoring of the Banggai cardinalfish trade, population and habitat, reveal a marked increase in compliance with current fish quarantine regulations and other improvements in *P. kauderni* fishery and trade practices. Monitoring and research data also reveal that key BCF micro-habitats (*Diadema* urchins and sea anemones) are under pressure from increasingly intensive harvesting as a side-effect of seaweed farming development. This is a new and serious threat to the sustainability of the fishery and the conservation outlook of the species, requiring an integrated ecological and social approach. Recent developments and options for addressing current challenges to a sustainable ornamental fishery will be presented.

13C Ecological effects of habitat degradation
Friday 13 July, 1015, Hall A

Changing feeding preferences of butterflyfishes following coral bleaching

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Reduction in the availability of live coral poses a significant threat to reef fishes, in particular to those highly specialized corallivorous species, which rely on corals to meet all of their nutritional needs. Corallivorous fishes often exhibit a reduction in feeding intensity upon bleached colonies, suggesting that nutritional quality of the coral declines following bleaching. However, this has never been tested. In the present study, coral bleaching was experimentally induced to test for changes in feeding preferences of coral-feeding butterflyfishes, and assess whether changes in prey preferences reflected changes in food quality, measured based on lipid content. The corallivorous butterflyfish *Chaetodon plebeius* and *Chaetodon lunulatus* reduced feeding on bleached coral colonies (*Pocillopora damicornis* and *Acropora spathulata*) compared with healthy colonies. Similarly, a significant decline in total lipid content was observed in *A. spathulata* following bleaching, suggesting that quality of prey may be the driving factor behind changing patterns of prey use. These data indicate that coral bleaching can have an immediate effect on the fitness of coral-feeding fishes, affecting prey preferences and food quality.

13C Ecological effects of habitat degradation
Thursday 12 July, 1215, Hall A

Projected changes in coral assemblages and effects on reef fishes

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Scleractinian corals are fundamental to the functioning of coral-reef ecosystems, contributing to primary production, nutrient recycling, and reef growth. Scleractinian corals are also the primary habitat-forming species in coral-reef habitats. Removal or destruction of corals will therefore profoundly alter the structure and dynamics of coral-reef habitats,

with potentially significant effects on highly diverse assemblages of species that associate with coral reefs. It is predicted, for example, reef systems that are devoid of corals will support 60-70% fewer species of the fishes compared to reefs with healthy coral growth, which has obvious ramifications for reef-based fisheries. It is unlikely however, that climate change will in itself cause global extinction of all scleractinian corals. More likely is that coral ecosystems will come to be dominated by a restricted suite of coral species that are either resistant to coral bleaching, or capable of rapid recovery in the aftermath of major disturbances. The purpose of this talk is to demonstrate likely changes to coral reef ecosystems due to ongoing climate change. The ultimate structure of coral assemblages will depend upon the severity versus frequency of coral bleaching (and other disturbance events), with concomitant effects on reef fish assemblages.

13C Ecological effects of habitat degradation
Thursday 12 July, 1000, Hall A

Macroecology of butterflyfish feeding behavior: what the generalists can tell?

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Butterflyfishes occur in a wide range of reef habitats, showing an intimate relationship with the substrate due to their specialized feeding behavior. Previous authors have highlighted the importance of their possible co-evolution with coral reefs, and the sensitivity of some clades to global coral decline. In the Western Atlantic, *Chaetodon striatus* exhibits a huge distribution range, from the Caribbean to Southern Brazil, encompassing different reef systems. This species is the most abundant Chaetodontidae along the Brazilian coast, while in the Caribbean *C. capistratus* prevails. We analyzed gut contents from 3 species (185 specimens) from 8 localities, from diverse coral reefs to marginal rocky reefs. *Chaetodon humeralis* (sister clade) from rocky reefs of the Tropical Eastern Pacific, feeds mostly upon Anthozoa and Polychaeta, in similar proportions. *Chaetodon capistratus* from Puerto Rico ingested mostly octocorals, while *C. striatus* showed a greater diet breadth, consuming mostly other anthozoans (e.g. zoanthids and scleractinians), Polychaeta, and Molluscan eggs. *C. striatus* showed greater consumption of anthozoans when it was abundant. However, when co-occurring with *C. capistratus*, it feeds mostly upon Polychaeta, probably indicating niche partitioning. Therefore, even a generalist Chaetodontidae, such as *C. striatus* retains traits of its evolutionary origin, picking polyps when available. Moreover, such generalist feeding behavior could represent higher resistance to reef phase shifts when compared to strict corallivory from many of its Indo-Pacific counterparts.

13C Ecological effects of habitat degradation
Friday 13 July, 1030, Hall A

Which environmental factors more importantly affect reef fish community structure?

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One of the important aims in coral reef ecology is to understand what environmental factors determine the structure of reef fish communities. To date, it is known that some abiotic and/or biotic factors influence the distribution and abundance of reef fishes. However, there are few studies that have investigated a wide ranging variety of environmental variables at the same time and compared their effects on fish communities. This study was conducted on 36 fringing coral slopes (about 7 m in depth) of Okinawa Island, southwestern Japan, from June to September 2011. The community compositions of reef fishes were assessed by a visual census along a total of 108 belt transects of 20×2 m (three transects in each slope). As environmental variables, water chemistry (e.g., pH, salinity, DO, turbidity), biogeochemical properties (C:N, C and N stable isotopic signatures) of fine particles, physical environmental variables (e.g., geomorphology at multiple spatial scales, current strength) and biotic variables (e.g., community compositions of sessile foundation species), were also estimated. We used multivariate statistical methods and assessed the relative importance of the studied factors for reef fish communities. The aim of this study was to determine a hierarchy of the environmental factors from the perspective of reef fish community assembly.

13C Ecological effects of habitat degradation
Thursday 12 July, 1230, Hall A

Recent regional changes in reef fish abundance on the Great Barrier Reef

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The abundance of animals usually declines following degradation of their habitat, and this is generally true for coral reef fishes and coral

cover. A recent meta-analysis of studies of reef fish populations from the Caribbean, found consistent declines in overall reef fish numbers in some subregions over the past 12 years, as well as region-wide declines in some functional groups of fishes. Coral cover has also declined over a similar period in the other data-rich reef province, Australia's Great Barrier Reef (GBR), though the rate of decline has varied among subregions. The AIMS monitoring program has also surveyed more than 200 species of reef fishes in a standard habitat at 47 reefs along and across the GBR, for 19 years. Similar analyses of these data from the GBR found that the abundance of all functional groups increased over the period. Predictably for such a large area, trends in abundance of functional groups varied among subregions and show damped responses to disturbances. This is important because several very large tropical cyclones have passed over the GBR in the past 3 years, damaging a large proportion of the reefs and the effects of this broad habitat destruction should become evident in the next round of surveys.

13C Ecological effects of habitat degradation
Thursday 12 July, 1245, Hall A

'Feng-Shui' under the sea: optimal microhabitat for coral trout recruits

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Recruitment is critical to the recovery and dynamics of fish populations, and this is especially true for exploited fishes, such as coral trout. Increasing evidence suggests that recruitment by fishes is limited not only by larval supply, but also the availability of suitable settlement habitats. The purpose of this study was to assess the specific habitat preferences for newly settled individuals of spotted coral trout (*Plectropomus maculatus*) in the Keppel Islands, Southern Great Barrier Reef. In particular, we wanted to assess whether coral trout were reliant on live coral. Field-based studies were complemented by experimental studies, to test the relative importance of habitat type versus prey availability in determining habitat use. We found that the compound-habitat, which includes live coral and sandy bottom, is the most preferred habitat for spotted coral trout recruits. We called it the 'beach house' hypothesis to distinguish it from the well-known 'edge effect' hypothesis. Experimental studies indicate that the shelter provided by coral is more important than the specific prey species. This information is useful to improve the efficiency of management strategies, such as marine protected areas, which may aid in the recovery and sustainable exploitation of coral trout.

13C Ecological effects of habitat degradation
P125

Do no-take marine reserves work on highly disturbed coral reefs?

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Coral reefs are under increasing threat from a number of factors including overfishing, habitat degradation, pollution and the cumulative impacts of climate change. In order to mitigate these impacts, networks of no-take marine reserves have been widely advocated and embraced as a means of conserving biodiversity, maintaining or restoring ecosystem function and productivity, and as a management tool for coral reef fisheries. Numerous studies have documented significant increases in the abundance, body size, biomass, reproductive potential and diversity of exploited species within reserves. Furthermore, there is increasing modeling and empirical data showing that networks of reserves can provide fishery benefits via spillover and recruitment subsidies to surrounding areas. There is little evidence however, that reserves provide protection against broad-scale disturbances such as coral bleaching events, cyclones or flood plumes. Here we provide an overview of recent findings from one of the few long-term monitoring studies assessing the ecological effects of no-take reserves within the Great Barrier Reef Marine Park. Across all monitoring locations, significant and persistent benefits have been detected for key fishery target species within reserve boundaries. However, in one region, a series of climate-driven disturbance events has led to major declines in hard coral cover, habitat complexity, fish species richness, numerical density and biomass in both reserves and fished zones. Although there is high potential for recovery, it is clear that major disturbances and subsequent declines in reef productivity may undermine many of the accrued benefits of no-take reserves.

13C Ecological effects of habitat degradation
Thursday 12 July, 1700, Hall A

13D Reef sharks & coral reefs

Movement patterns of apex predators at a pristine coral atoll

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Sharks and other apex predators have shown dramatic declines on coral reefs worldwide, due to overfishing and loss of habitat. One important tool in the conservation of predator populations, is the establishment of Marine Protected Areas (MPAs). The establishment of effective MPAs requires a detailed understanding of predator movement patterns and how these vary seasonally and with habitat. Most studies of predator movements take place on already highly impacted reefs or in relatively small MPAs. We used acoustic telemetry to quantify the movement patterns of four species of predators in a relatively large, and unimpacted Pacific atoll, Palmyra Atoll. Blacktip reef sharks (*Carcharhinus melanopterus*) occupy both lagoon sand flats, backreef and shallow forereef habitats and have smaller home ranges, while Grey reef sharks (*C. amblyrhynchos*) used primarily forereef habitats. Both shark species are less mobile than Giant trevally (*Caranx ignobilis*) which utilize all habitats across the entire atoll. Snapper (*Lutjanus bohar*) used the smallest areas remaining within 1 km of where they were tagged. The structuring of spatial/habitat use patterns is particularly crucial for understanding predator dominated coral reef ecosystems, where the behavioral response of prey to predators appears to largely dictate the resulting ecosystem trophic structure.

13D Reef sharks & coral reefs
Monday 9 July, 1545, Hall A

Where do reef sharks go when they're not on reefs?

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Reef sharks are thought to play important ecological roles in coral reef environments. Some reef shark populations have been significantly affected by human activities, with declines reported from numerous locations, prompting renewed research and management interest. While most reef shark studies are focused on coral reef environments, some reef sharks also occur in non-reef habitats. However, their use of these habitats is poorly understood. This study examines the interactions between reef sharks and non-reef habitats in the Great Barrier Reef lagoon using fisheries data, tagging data and acoustic telemetry. These data reveal that several reef shark species occur in non-reef environments. Species such as the blacktip reef shark show evidence of population structuring and use of coastal non-reef habitats for critical life stages such as mating, pupping and as nurseries. These data also suggest that blacktip reef sharks have a dispersal phase where juveniles leave inshore, non-reef environments and move to new locations, including movements of up to 80 km to mid-shelf coral reefs. These movement and habitat use patterns increase the exposure of these species to risks and cumulative impacts. They also suggest that non-reef environments may play important roles in sustaining some reef shark populations, illustrate linkages between coastal environments and offshore coral reefs, and imply that reef sharks may also play important ecological roles in non-reef habitats. These complex habitat use patterns also have important implications for survey design in reef shark field studies, assessing marine park effectiveness, and reef shark conservation.

13D Reef sharks & coral reefs
Monday 9 July, 1000, Hall A

Acoustic monitoring of a Red Sea whale shark aggregation

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The whale shark (*Rhincodon typus*) is a large pelagic filter-feeder, which is cosmopolitan in tropical and warm temperate seas. Available data for this species are limited in general, and Red Sea populations are virtually unstudied. In 2009, an aggregation of immature whale sharks was discovered on Rope Reef, a nearshore coral reef in the central Saudi Arabian Red Sea. In March-May 2010, 32 acoustic receivers were installed on and around the site and 37 whale sharks (13 male, 13 female, 11 undetermined) were fitted with acoustic transmitters (Vemco V16P tags). Preliminary analysis shows 85% of all detections have occurred in April or May (26%

of total effort). Over 90% of detections were made by receivers installed on Rope Reef (40% of total effort). More than half of Rope Reef detections occurred at the northwest corner of the reef (25% of total effort). Of the 37 whale sharks tagged in 2010, 12 have been detected again in 2011. Describing the characteristics of this aggregation provides a baseline by which to guide the efforts of future whale shark studies in the area, and to inform local conservation efforts. It can be considered an important first step toward understanding both the local dynamics of Red Sea whale sharks and how they fit into the larger global population. We will present further analysis on gender specific differences and diel behavior. An additional 27 sharks were tagged in 2011, and another aggregation season is expected prior to ICRS 2012.

13D Reef sharks & coral reefs
Monday 9 July, 1530, Hall A

Estimating the abundance of apex predators: a comparison of methods

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There is mounting evidence of substantial and ongoing declines in populations of apex predators on coral reefs worldwide, with direct consequences for fisheries and tourism as well as potentially serious indirect consequences for the structure and function of reef ecosystems. The ability to accurately census and monitor populations of apex predators is paramount for their effective conservation and management. However, consensus is lacking regarding the reliability of census methods, which distracts conservation and management efforts. To address this issue, we evaluated the utility of four traditional and two novel methods of estimating abundance of reef sharks, which are apex predators on the Great Barrier Reef, Australia. Furthermore, we repeated this evaluation across a spatial gradient of human interaction (fished, unfished, and no-entry reefs) to quantify any potential bias caused by learned behavior of reef sharks towards humans. Timed-swims, manta-tows, catch-per-unit-effort (CPUE), catch-mark-recapture (CMR), baited remote underwater video (BRUV) and audible stationary counts (ASC) each detected a subset of the shark species present, with varying degrees of reliability and efficiency. However, the diver-based methods (timed-swims and manta-tows) were optimal because they yielded adequately reliable estimates of abundance, were minimally influenced by sharks' prior opportunities for interactions with humans, and had the advantage of being quick and easy to perform. These results should lead to a greater acceptance of previous and future research that utilizes diver-based census methods. This is critical given the threats facing apex predators and the need for effective management regimes based on defensible census methods

13D Reef sharks & coral reefs
Monday 9 July, 1515, Hall A

The importance of fish spawning aggregations to reef-associated sharks

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Reef fish spawning aggregations and reef-associated sharks are increasingly becoming trigger points for site based and species focused conservation measures, yet sparse information exists on the relationship between the two. Underwater visual monitoring and the deployment of acoustic arrays coupled with the acoustic tagging of both predators and prey suggest strong seasonal linkages and dependence of four species of reef-associated sharks on spawning reef fish. Movements of sharks were tracked inside and beyond five spawning aggregation sites and marine protected area boundaries located in Belize, Central America and Pohnpei, Micronesia. In the Caribbean, *Carcharhinus perezi* demonstrated preferential visitation rates to three sites on Lighthouse Reef Atoll, Belize that support reproductive aggregations of *Epinephelus striatus*, *Lutjanus cyanopterus* and *Mycteroperca tigris* respectively. Gladden Spit Marine Reserve, Belize, hosts strong seasonal site fidelity of *C. leucas* and *Rhincodon typus* that target different two life stages of *L. cyanopterus*, *L. jocu* and *L. analis* that aggregate to spawn. In the Pacific, *C. amblyrhynchos* females demonstrated strong site fidelity to the Kephara Marine Reserve in Pohnpei during the peak aggregations of *Epinephelus fuscoguttatus*, occurring prior to the known period of parturition. Following cessation of spawning events, sharks altered visitation patterns to spawning aggregation sites, occasionally undertaking broad movements to other feeding grounds. We demonstrate that the predictable dependence of reef-associated sharks on reef fish spawning aggregations provides the basis for non-consumptive economic alternatives to fisheries through tourism, and a cost-effective solution to the conservation of reef-associated predators.

13D Reef sharks & coral reefs
Monday 9 July, 1700, Hall A

Coral reefs: apex predator paradise or mesopredator nirvana?

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The role of predators has been well defined within terrestrial literature but the criteria applied to those definitions are rarely transferred to marine systems. Thus sharks are often described as apex predators regardless of whether they meet the characteristics of this designation. Accurate description of the predatory role of a species has direct implications for understanding the role of that predator within the system. For example, apex predators exert acute, top down control while mesopredators provide more diffuse impacts. Reductions in these two different types of predation can cause different effects within an ecosystem. Exploitation of apex predators has been shown to cause mesopredator release in terrestrial systems, which have ecosystem level consequences, while loss of mesopredators plays a less significant role. Indeed all of this is complicated by ontogenetic diet shifts widespread among the indeterminate life histories of the species that dominate aquatic ecosystems. Here we consider coral reefs as a case study for predation effects by shark species within the context of apex and mesopredators. The implications of fishing effects and marine protected zones will be discussed within the context of reef ecosystems and the role of sharks as predators within these environments.

13D Reef sharks & coral reefs
Monday 9 July, 1145, Hall A

Taken out of context: the effects of shark removal in the dynamic environment of a coral reef

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Sharks are experiencing rapid world-wide declines in coral reef ecosystems. Our knowledge of the role of sharks in structuring fish communities is limited, although recent evidence suggests that a high biomass of top-order predators including sharks promotes a very different community structure of fishes in comparison to reefs where they are absent. However, this view stems from studies that have sampled snapshots of fish abundance on reefs and does not account for the role of other process such as cyclones, bleaching and coral disease, in driving patterns of composition. Here, we use the results of a long-term (decadal) monitoring program to investigate the relative effects of top-down (sharks and other predators) and bottom-up (cyclones, bleaching) processes as determinants of fish community structure on atoll reefs off the north west coast of Australia. Reefs subject to intense, targeted fishing for sharks had fewer sharks of only a restricted number of species in comparison to unfished reefs. On fished reefs, we found evidence of mesopredator release and a trophic cascade that was propagated down the food chain to primary consumers. Simultaneously, the effects of bottom-up processes of bleaching and cyclones were propagated up the food chain to corallivores, planktivores and herbivores, but did not affect carnivores. Consequences of the loss of apex predators were discernable above the changes created by bottom-up processes and were likely to have important implications for the recovery of reefs from disturbance events that remove cover of live coral.

13D Reef sharks & coral reefs
Monday 9 July, 1215, Hall A

Inferring social behaviour and mating patterns in a reef shark from social network and molecular analyses

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Reef-associated sharks often show strong patterns of site fidelity that could be viewed as a prerequisite for sociality. Yet there is limited empirical evidence that such grouping is socially driven. Much less is known about the interplay between dispersal strategies, genetic structure and social behaviour. Understanding the driving forces behind the structural properties of shark populations has become a challenge. We used a social network approach that integrates associations of several individual blacktip reef sharks (*Carcharhinus melanopterus*) over a 3-year period in Moorea (French Polynesia) to demonstrate that the population was structured into communities. We confronted the resulting structure with candidate explanatory variables such as sex, size or genetic relatedness. Individuals maintained non-random and long-term relationships that are governed by specific factors. As the mating system and dispersal strategies are major mechanisms driving population structure, we also used parentage

analysis to infer breeding patterns and connectivity. Females migrated for parturition to specific nursery areas for which they tended to be philopatric. Mating was globally random despite a high proportion of inbreeding suggesting reduced population size or specific mating behaviour. Our findings highlight that shark population structure can be complex, and that other studies on shark aggregations may benefit from such fine-scale analytical approaches in order to better understand the causes and consequences of group living in these top predators.

13D Reef sharks & coral reefs
Monday 9 July, 1630, Hall A

Oceanic sharks visit a coral reef for cleaning

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Interactions between pelagic thresher sharks (*Alopias pelagicus*) and cleaner wrasse were investigated on a coral reef seamount in the Philippines. The interactions at this site may explain why these mainly oceanic sharks venture into shallow coastal waters where they are vulnerable to disturbance from human activity. From 936 hours of observations, recorded by remote video camera between April 2008 and December 2009, 93 cleaner-thresher shark events were analyzed. Observations of pelagic thresher sharks interacting with cleaners at the seamount were recorded at all times of day, but their frequency declined gradually from morning until evening. Cleaners showed preferences for foraging on specific areas of a thresher shark's body. For all events combined, cleaners were observed to conduct 2,757 inspections, of which 33.9% took place on the shark's pelvis, 23.3% on the pectoral fins, 22.3% on the caudal fin, 8.6% on the body, 8.3% on the head, 2.1% on the dorsal fin, and 1.5% on the gills respectively. There was a direct correlation between the amount of time a thresher shark spent at a cleaning station and the number of inspections it received. Thresher shark clients modified their behaviour by circular-stance-swimming, to facilitate cleaner inspections. The cleaner-thresher shark association reflected known behavioural trends in the cleaner-reef teleost system, since cleaners appeared to forage selectively on shark clients. In addition to acting as social refuges and foraging grounds for large visiting marine predators, coral reefs on seamounts may also support pelagic ecology by functioning as cleaning stations for oceanic sharks and rays.

13D Reef sharks & coral reefs
Monday 9 July, 1645, Hall A

Comparative abundance of reef sharks in the Western Indian Ocean

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Over the last four years we have conducted surveys to assess the abundance of sharks on coral reefs at disparate sites through the Western Indian Ocean, including the Jeddah area of the Red Sea, the isolated islands of Bassas da India, Europa and Aldabra, the granitic Seychelles and the southern three atolls of the Maldives. Two methods were used: direct observation by SCUBA divers following chumming and Baited Remote Underwater Video Stations (BRUVS). These two methods produced contrasting though complementary data. Three findings emerged: i) in all locations the largest predatory sharks such as tiger shark, *Galeocerdo cuvier*, appeared either scarce or absent, ii) in some locations, especially those receiving a degree of protection, medium-sized sharks such as black-tip reef sharks, *Carcharhinus melanopterus*, and grey reef sharks, *Carcharhinus amblyrhynchos*, could be relatively abundant, but iii) the most abundant species varied considerably between study areas, with for example Silky Sharks, *Carcharhinus falciformis*, being most abundant on reefs near Jeddah and Galapagos shark, *Carcharhinus galapagensis,* the most abundant at Bassas da India. The scarcity of large sharks seems most likely related to shark fishing activities, while the relative abundance of medium-sized sharks may reflect reduced predation by, or competition from larger species, with the species favoured depending on habitat factors, such as the presence of extensive lagoons. The region with the most typical shark community appeared to be the southern atolls of Maldives, which were also judged to have the most natural reef assemblages.

13D Reef sharks & coral reefs
Monday 9 July, 1115, Hall A

Apex predators and human populations as structuring agents on coral reefs

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Fishing by humans and the presence of top-order predators are thought to have important but contrasting effects on the structure and abundance of communities of coral reef fishes. Broad-scale surveys (1000s km), across geographic gradients of human population and shark abundance on coral reefs, offer an opportunity to assess the relative and synergistic effects of these top-down processes in structuring reef fish faunas. Our study utilizes a comprehensive survey of coral reefs across the Pacific that included benthic surveys and abundance counts of reef fishes, from 17 countries and 63 communities from Palau to French Polynesia (n = 1650). This dataset was analysed to examine the roles of top-order predators and human demography as structuring agents of communities of coral reef fishes. We used logistic Geographically Weighted Regression to reveal that reefs in the eastern Pacific have a stronger relationship (i.e. local high R-squared) between human demography and shark distribution than reefs in the western Pacific. Further, reef shark distribution was significantly related to the physical structure of the reef (e.g. atoll, no lagoon, etc.). Using regression tree analysis, we reveal that atolls with less than 5.5 people within 10 km of sites, display a community trophic structure that is different to that of sites with higher human population densities. Finally, structural equation models reveal that top-down and bottom-up mechanisms both contribute significantly to these patterns. Our findings stress that human activity, sharks and benthic habitat are all important factors structuring fish communities in coral reef ecosystems throughout the Pacific.

13D Reef sharks & coral reefs
Monday 9 July, 1130, Hall A

The role of non-resident sharks in shaping coral reef communities

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The importance of sharks in shaping coral reef communities, and the effects of declines in reef shark numbers, has received increased attention in recent times. Relevant research has focused on reef-resident species of shark, most notably grey reef (*Carcharhinus amblyrhynchos*), whitetip reef (*Triaenodon obesus*) and blacktip reef (*Carcharhinus melanopterus*) sharks. However, a range of other shark species occur around and within coral reefs, and may play an important role as predators of resident reef invertebrates, fish and sharks. This predation may have both direct and indirect effects on the functioning of coral reef communities. Catch data from reefs in the southern Great Barrier Reef indicates that species such as tiger (*Galeocerdo cuvier*), sandbar (*Carcharhinus plumbeus*), blacktip (*Carcharhinus limbatus*), bull (*Carchahinus leucas*) and weasel (*Hemigaleus australiensis)* sharks, regularly occupy coral reef ecosystems in which they may play important roles. Evidence from stable isotopes of carbon and nitrogen will be presented to examine the importance of reef environments in providing food for non-resident species. Acoustic monitoring data that show the space use of non-resident species will also be presented. The results of this preliminary work indicates that the role of non-resident shark species is far greater than previously anticipated, and may be an important consideration in the management of coral reef ecosystems.

13D Reef sharks & coral reefs
Monday 9 July, 1015, Hall A

The current status of sharks in the Red Sea

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The Red Sea arguably contains the most biologically diverse and unique coral reefs outside of the Coral Triangle. While reef health in general remains relatively high, there is a surprising dearth of larger apex predators such as sharks. Urgently needed management of shark populations is being hampered by the paucity of available information on almost all aspects of Red Sea elasmobranch biology, ecology, and population dynamics. To promote scientific efforts to conserve and sustainably manage shark populations in the Red Sea we have incorporated Baited Remote Underwater Video Surveys (BRUVS), long-line sampling, and market survey data with information from ongoing shark tagging and genetic studies. BRUVS in Saudi Arabian inshore and offshore reefs, in conjunction with long-line surveys, revealed a dramatic lack of reef-associated sharks. Catch per unit effort for Saudi Arabian Red Sea BRUVS ranges between 10 - 60 times lower than data available for the Atlantic, Pacific and Indian Ocean. Despite the apparent scarcity of apex predators, relatively large quantities of reef-associated and pelagic

sharks can be found in the fish markets in the region, suggesting heavy fishing pressure on existing populations. We will present a compilation of Red Sea survey data from Saudi Arabia, Egypt, and Sudan. These data allow for the establishment of a baseline on the current status of Red Sea shark populations, serving as a foundation for future studies on these historically overlooked stocks.

13D Reef sharks & coral reefs
Monday 9 July, 1030, Hall A

Marine parks for reef sharks: shark movements at Ningaloo Reef

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Recent declines in reef shark populations have caused concern for marine ecosystem consequences, and subsequently marine protected areas have been proposed as a means of slowing this trend. Unfortunately our knowledge of long-term reef shark movement for most species is poor, which is essential for designing effective marine parks. We tagged 83 sharks of four species with acoustic transmitters and used a network of 103 receivers at Ningaloo Reef to determine the effectiveness of current protection. We analysed the spatial and temporal movement of 12 individuals (*C. melanopterus* [n=7]), *C. amblyrhynchos* [n=2), and *N. acutidens* [n=3]) over one year around a sanctuary zone within the marine park. All individuals were detected within the array at Mangrove Bay <40% of the time throughout the year. Furthermore, *C. amblyrhynchos* had <1% of position estimates within the sanctuary zone, compared to C. *melanopterus* adults that ranged between 0 and 99 %. Juveniles of both species of *C. melanopterus* and *N. acutidens* had relatively high percentages of position estimates in the sanctuary zone (84-99%). Kernel density hotspots for *C. melanopterus* and *C. amblyrhynchos* were identified outside of the sanctuary zones, and mean home range estimates (MCP) for adults of these species was 12.77 km^2 (± 3.12 SE) and 19.56 km^2 (± 2.26) respectively. Home ranges were smaller for juvenile *C. melanopterus* (7.17 km^2 ± 1.33) and juvenile *N. acutidens* 0.61 km^2 (± 0.04). Long-distance movements were observed in adult *C. melanopterus* and *C. amblyrhynchos*, the longest being 137 km.

13D Reef sharks & coral reefs
Monday 9 July, 1500, Hall A

'Sharkwatch' Maldives

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Sharks are top predators playing an important ecological role on coral reefs. Due to their slow growth, late maturity and low fecundity, sharks are very vulnerable to over-exploitation. Historically fished in the Maldives for their liver oil, the fishery intensified in the late 1970s because of the value of dried shark's fin and salted shark meat as export commodities. After 1975, the estimated annual shark catch of 575 metric tonnes (MT) rose rapidly to 1500 MT, and subsequently fluctuated between 1100 MT and 2000 MT annually until 1998, when a 10 year moratorium on all types of shark fishing inside and within 12 miles of 7 major 'tourism' atolls was declared, in order to minimize the conflict between the shark fishery and the tourism industry. However, shark sighting reports continued to decline, leading to the eventual ban of shark fishing inside and within 12 miles of the outer atoll rims of all atolls of the Maldives in 2009, and a total ban on shark fishing from Maldivian waters in 2010. 'Sharkwatch', with the participation of the tourism industry and resorts, was launched in July 2009 to collect baseline information and monitor the outcomes and effectiveness of the ban. This is the first time that stock surveys have been attempted in the Maldives, and the data collected will be invaluable in providing a better understanding of the current population of reef shark species and the effectiveness of recently implemented management measures.

13D Reef sharks & coral reefs
P126

Evidence of fragmented reef shark populations in the insular Pacific

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Sharks have been emphasized as keystone species driving the evolution of marine ecosystems. Their dispersal capacity is limited to adulthood and little is known about the connectivity between different populations. Present work, based for the first time on microsatellite analysis of shark populations in a fragmented environment, has revealed the presence of a strong genetic structure in the

blacktip reef shark (*Carcharhinus melanopterus*) populations within a restricted area, here in French Polynesia. Both Bayesian and FST analysis revealed three to four separate genetic populations that coincide with an island or a small group of islands. This demonstrates evidence of a low dispersal capacity of this species, and the importance of maintaining a sustainable reproductive population for each isolated population in a fragmented environment, such as the Pacific oceanic islands. Thus, considering sharks in future management plans leads us to recommend adapting MPA designs by integrating biological and geographical characteristics.

13D Reef sharks & coral reefs
Monday 9 July, 1200, Hall A

13E Fisheries

The way forward of fishermen in the fishing industry

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Fishing is the oldest profession on earth, but methods need to be reviewed and improved regularly to suit fishermen in the modern world; there have been several accidents at sea, which may have been preventable with preplanning, but were unpreventable by the fishermen in the current fishing context. It is important to secure fisherman safety at sea, as the way forward for the fishing industry. In fact, there have been several attempts by the fishermen to deal with such problems, but they proved futile due to the lack of external support. It is necessary to address fishermen safety with government authorities, and with grassroots efforts among the fishermen. Fishermen safety is of such importance that national safety at sea or safety for fishermen bodies need to be initiated with other organizations, governmental agencies, the private sector and stakeholders such as fisheries authorities, coastguard/navy, port authority, meteorological department, health authorities and wives and families of fishermen. Lastly, fishermen need to consult experts in their fishery tools and equipment to prevent accidents that occur at sea.

13E Fisheries
P127

Overexploited but underreported: ground truthing fish catches using Google Earth

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Coral reef fisheries are exploited at unprecedented rates, yet catches reported to the Food and Agriculture Organization (FAO) remains unreliable. In the wake of global overfishing, negligent reporting has a strong influence on fishery policy and food security. So what solutions can we propose for improving the quality of catch statistics? In the Persian Gulf, weirs (Arabic: hadras) have been used for thousands of years as a form of passive fishing gear. These semi-permanent traps are constructed at (or just below) the low tide mark; as reef species (anchovies, shad, seabreams, sharks, etc.) complete their diel feeding migration from coral reefs to mudflats, they are captured in the weirs by the receding tides. This study examines recent advances in satellite technology that allow weirs to be viewed off the coast of six countries using imagery available through Google Earth. Combining data derived from satellite images with assumptions about effort, species selectivity, and tidal differences, we approximate catches and compare our results to FAO statistics. The results speak to the reliability of reported catches in the Gulf, and provide the first example of ground truthing capture fisheries using satellite imagery.

13E Fisheries
Wednesday 11 July, 1745, Hall A

Are the ecological and political spatial scales of fisheries compatible?

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The spatial scale of larval dispersal strongly influences the ecologically relevant spatial scale for fisheries management. In many places, local communities have customary ownership of reefs (customary marine tenure [CMT]), which establishes user-rights boundaries between communities, thereby providing the politically relevant spatial scale for management and conservation. A key unanswered question is whether these two spatial scales are compatible. Does community-based fisheries management result in recruitment benefits for that community, or do larvae disperse to other community tenure areas, thereby exporting management benefits? Using genetic parentage analysis, we resolved patterns of larval dispersal and recruitment derived from a coral trout (*Plectropomus areolatus*) spawning aggregation on the south coast of Manus, Papua New Guinea. We sampled adults at the aggregation and juveniles from a 75 km stretch of coastline centered on the aggregation that

included the CMT estates of five communities. Most recruitment benefits were retained within the CMT estate that included the spawning aggregation, with substantial export to the other four CMT areas: an estimated 33% of recruitment to the CMT containing the aggregation was derived from that aggregation, and adjacent CMTs received between 12% and 25% of their recruitment from that aggregation. Considering contributions from other unsampled aggregations in the study area, our findings suggest a largely closed, self-sustaining metapopulation. Our results indicate that ecological and political spatial scales can be compatible and that local management can lead to local benefits - a powerful argument for community-based fisheries management and conservation.

13E Fisheries
Wednesday 11 July, 0930, Hall A

Fishery reserve effects on sparid recruitment along French Mediterranean coasts

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Many studies have reported increasing trends in fish abundance and biomass inside marine reserves. This 'reserve effect' may lead to increased fecundity and production inside the reserve, enhancing recruitment in surrounding areas. However, the increase in piscivores and other large carnivores (i.e. predators) could also translate to higher predation inside the reserve, thus lowering recruitment. In this study, juvenile *Diplodus sargus* (Sparidae) were surveyed in their nursery habitats in Saint-Raphäel, French Mediterranean to determine the effects of protection on their abundance and mortality. Visual census was done weekly during the recruitment season (June to August 2011) in 12 nursery coves situated across three zones: inside the Cantonnement de Pêche du Cap Roux (Cap Roux Fishery Reserve), north and south of the reserve. Significant differences were observed in juvenile abundance among zones (1-way ANOVA, $p=0.009$). The number of juveniles was highest in the south and lowest inside the reserve. These patterns could be due to site characteristics, larval supply or predation, but post-settlement migration can be ruled out because *D. sargus* at this stage, stay in their nurseries. When abundance (log-transformed) was plotted over time, mortality rate was highest inside the reserve and lowest in the south, although the differences were not statistically significant (1-way ANOVA, $p=0.062$). This study shows that recruitment of the rocky reef fish, *D. sargus*, is lower inside the reserve compared to fished areas and that predation could be causing this pattern, suggesting that protection effects on fish recruitment may be more substantial than previously expected.

13E Fisheries
Wednesday 11 July, 1130, Hall A

Spear-fishing pressure on a source of reef resilience in Micronesia

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Grazing fish constitute a critical source of reef resilience yet are traditionally some of the main targets of spear-fisheries in Micronesia. In a world of climatic challenges, managers require a solid rationale to protect populations sustaining processes that increase the chances of reefs recovering from disturbance. This study characterised the spear-fishery of grazing fish in Palau, Pohnpei and Guam to identify the main threats to resilience resulting from impaired grazing due to potential overfishing, and the main risks of losing populations of high socio-economical value. Enhancing the existing arguments in favour of managing grazers was our ultimate goal. 52 species were present in the catch sold at local markets. Countries differed in the amount of fishing effort, species composition and catch per unit effort (CPUE). Guam yielded the highest CPUE in weight (7.5 kg fisher^{-1} hour^{-1}) resulting from a deep SCUBA spear-fishery focused on the large browser Naso unicornis, whereas Pohnpei yielded the most numerous catch (10.8 individuals fisher^{-1} hour^{-1}) with an outstanding proportion of rabbitfish. Main targets throughout Micronesia included two macroalgal browsers (*N. unicornis* and *N. lituratus*), a scraper (*Hipposcarus longiceps*) and a detritivore (*Siganus punctatus*). Size classes under the known length at first maturity were often caught disproportionally in Pohnpei. The comparative analysis of species-specific metrics of fishing pressure, grazing function and vulnerability to fishing provided evidence to warrant widening the scope of management measures seeking to enhance the resilience of Micronesian reefs, and improve the chance of preserving culturally important resources for the future.

13E Fisheries
Wednesday 11 July, 1040, Hall A

Stock assessment of sea cucumbers on Guam, Micronesia.

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Sea cucumbers (Holothuroidea) are commercially valuable echinoderms found in abundance on many tropical reefs. Holothuroids used for food are known as trepang or beche-de-mer, and demand for them has led to collapse of sea-cucumber populations in several island ecosystems. To prevent overharvesting on Guam, in the Mariana Islands, Micronesia, we have begun a comprehensive stock assessment of the population structure of commercially important species. We are also exploring the role of marine protected areas in the management of holothuroids. Stock surveys are done using transects, timed swims and length measurements done *in situ*. Preliminary findings include the possibility of a small sustainable fishery for several species and evidence of the overharvesting of some species by subsistence fishermen. Our goal is to establish the circum-island distribution of species and provide the government of Guam with a management plan for the sustainable harvest of sea cucumbers.

13E Fisheries
P128

Fishing down the herbivores and reef vulnerability

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Artisanal fishing can have major impacts on the structure and function of coral reef ecosystems. By removing particular fish functional groups, artisanal fishing may not only distort reef food webs, but may also lead to a disruption of ecosystem function and ultimately a shift in benthic community structure. Overfishing of herbivores is particularly detrimental, and has been linked to shifts from coral- to macroalgal-dominance in several locations. An understanding of how fishing-induced changes in reef fish trophic structure relates to the resilience of reefs to disturbances, is important to develop management options that avoid undesirable ecosystem-level changes. This study investigates the impact of artisanal fishing on the demographic structure and biomass of three important functional groups of herbivores (grazers, scrapers and excavators) and other trophic groups of reef fishes, at coral-dominated reefs inside and outside marine protected areas in Aceh (northern Sumatra, Indonesia). Using a 5-yr dataset (2006-2011) we investigate the relationship between fishing pressure at 10 fishing grounds on Weh and Aceh Islands to determine if fishing pressure was directly impacting the biomass and trophic structure of reef fish. We also take advantage of a mass coral bleaching event that caused widespread mortality of shallow water corals in 2010 to explore the relationships between the trophic structure of reef fish assemblages and the mortality, and subsequent recovery, of coral populations. The information from this study is being used to develop fisheries controls in areas of highest herbivore removal and assist with the post-bleaching recovery of shallow Acehnese reefs.

13E Fisheries
Wednesday 11 July, 1145, Hall A

Co-management of tropical coastal social-ecological systems

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Two hundred million people depend on small-scale fisheries for their livelihoods-overwhelmingly in developing countries, where insufficient resources and weak governance challenge the capacity of governments to implement effective resource management. In an effort to deliver better outcomes for people and the ecosystems they depend on, many governments are engaging resource users in collaborative arrangements (frequently called co-management), that provide local people with a greater say in the allocation and use of natural resources. Yet few empirical studies have demonstrated the social and institutional conditions conducive to successful co-management outcomes, especially in small-scale fisheries. Here, we evaluate 43 fishery co-management arrangements across five countries and show: i) co-management is largely successful at meeting ecological and social goals; ii) fishery overexploitation is most strongly influenced by market access and users dependence on resources; iii) co-management tends to benefit wealthier resource users; and iv) institutional characteristics strongly influence livelihood and compliance outcomes, yet have little effect on ecological conditions. This study provides empirical evidence that co-management can sustain fisheries and the people that depend on them, even in the social-ecological contexts most susceptible to failure: artisanal, multi-species, coastal fisheries in low-income countries. However, the likelihood of this happening is higher when certain social, economic, and institutional conditions are in place. Managers and donors can facilitate desirable co-management outcomes by working with resource users on context-dependent strategies to improve livelihoods and governance, but these should be implemented in conjunction with complementary initiatives that address the

threats to marine ecosystems arising at larger scales.

13E Fisheries
Wednesday 11 July, 1630, Hall A

The ecological effects of exploitation on coral reefs

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Overfishing is one of the main sources of exploitation on coral reefs, and the consequences include altered function, resilience and diversity. Fishing traps are unselective, catching anything that is small enough to enter but larger than the mesh size; hence juveniles and important species are extracted unnecessarily. Escape slots were trialed in Kibuyuni, Kenya, for 2 cm, 4 cm, 6 cm, and 8 cm slot sizes. Preliminary data indicate a prominent change in the functional composition with different slots. The proportion of browsers was a third of the control for the 2 & 4 cm, and were absent from the 6 cm. Grazers/detritivores were two and a half times as abundant in the 2 cm compared to the control. Scrapers/small excavators were also found in the highest proportion in the 2 cm and declined as the slots increased in size. The 8 cm was comprised entirely of invertivores. The mean size of fish increased over the first four slot sizes, 0=19.49 cm, 2=20.97 cm, 3=22.79 cm, 4=24.22 cm, 8=18.02 cm. However this is not caused by more fish in larger size classes but less small fish being retained in the experimental traps. Revenue and weight of fish per trap exhibit a marked decline as the slot size increases; Price: $49, $24, $9, $0.5, $2 USD; Weight: 51 kg, 25 kg, 8 kg, 0.5 kg, 2 kg. To date 58% of the fish catch has consisted of *Scarus ghobban*, *Naso brevirostris*, *Siganus sutor*, *Siganus stellatus*, and *Plectorhinchus sordidus*. In addition, life history characteristics are used to predict how long the local fish population will take to grow into the next size of escape slot.

13E Fisheries
Wednesday 11 July, 1530, Hall A

Reef fishes movement patterns in Martinique: is MPA design efficient?

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MPAs are one of the tools most used to preserve marine resources and habitats. Their effectiveness is highly dependent on coral fish movement ability and their daily and seasonal behavior. This project investigated home range size and diel behavior patterns of 4 coral fish species (*Acanthurus chirurgus*, *Lutjanus apodus* and *Sparisoma viride*) using external (1040 fishes tagged) and acoustic telemetry (110 fishes tagged) tagging methods. A network of 30 acoustic receivers was deployed in the MPA (Marine Protected Area) Robert Bay (Martinique) for two years. Results from the acoustic tagging method showed that three species exhibited limited movements inside the MPA suggesting that they are relatively sedentary within their reef habitat. This indicates that the MPA size appears well designed to conserve fish populations. However, the use of external tags associated with recaptured fishes data indicated that some individuals moved off the MPA boundary and surprisingly travel long distance (>10 km) in a short time period (2-3 days). While the reason of such long travelled distance is not yet well understood, this suggests that MPA size design may be too small to optimally protect fishes. This project clearly highlights that 1) local fish movement patterns are more complex than expected and 2) the method of tagging may influence our understanding of fish movements and induce bias in the interpretation of studies investigating MPA efficiency. As such, further work is needed to combine external and acoustic tagging methods to gain deeper and better knowledge on fish movement capacity.

13E Fisheries
Wednesday 11 July, 1200, Hall A

Poor efficiency and rapid expansion of Vietnamese sea cage aquaculture

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During the last decades global aquaculture production has rapidly increased. Initially, aquaculture was thought to be a solution to limited food resources. However, consumer preference for carnivorous fish species and inefficient fish feed constitute global problems, as more fish are incorporated into the system than are removed from it. Vietnam is among the largest producers of cultured fish in the world (3rd place, FOA). In the program for aquaculture in Vietnam 2000-2010, the Ministry of Fisheries suggested that aquaculture should produce large fish with 'high market value'. This plan, along with raised global demands, and regional economic development have underpinned the growth of the sea cage aquaculture industry along the Vietnamese coast. In order to establish the state of Vietnamese sea cage aquaculture development over the last decade, the present study used remote sensing data (to follow expansion of aquaculture) combined with semi

quantitative interviews. The results showed that the majority (>90%) of fish and lobster farms use 'trash fish' as feed (TFF). Use of TFF results in remarkably low feed conversion ratios (FCR), <1/30 compared to average pellet fed farmed salmon or carp (FCR from 1/2 to 1/0.47). Additionally use of TFF causes higher prevalence of diseases, poorer water quality (threatening the high diversity coral reefs (420 species locally)), and increased pressure on wild fish stock. The products are mainly used for export. The study discusses long and short term consequences of TFF practice and potentially alternative more sustainable farming methods.

13E Fisheries
Wednesday 11 July, 1645, Hall A

Sustainable utilization strategy on ornamental reef fish resources in Weh Island, Aceh

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The ornamental reef fishery of Weh Island began in 1997, yet no assessment of reef fish resources, potential species for trade, and their sustainable yields has been made. This study assesses the sustainable catch quota of potential ornamental reef fish species, and provides optimum utilization strategies based on sustainable catch quotas, price, and effort capacity. Seventy-seven ornamental reef fish species were identified from underwater visual census at 20 sites in the marine waters of Weh Island. Catch and effort data were recorded for 12 months in 2010. Nineteen species of ornamental fish were landed by local fishers, and 83% of the total catch was comprised of the Powder Blue Tang (*Acanthurus leucosternon*). The maximum sustainable yield (MSY) of ornamental fish species was assessed using a surplus production model, with an annual catch quota set at 80% of MSY. From catch data, we found that the harvest level of Powder Blue Tang in 2010 exceeded its annual catch quota (103.5%), while the other 18 species were still under harvested. Optimization results using the Linear Programming suggested that increasing catch of three species, *Acanthurus tenneti*, *Paracanthurus hepatus*, and *Pomacanthus imperator* was required to achieve maximum economic yield. The ornamental reef fishery of Weh Island has the potential, to achieve economic yields of around 5.6 billion rupiah (~$620,000) annually. Based on sustainable catch quotas and financial analysis we conclude that the ornamental reef fishery of Weh Island can be managed sustainably and achieve positive ecological and economic outcomes.

13E Fisheries
P129

Moluccas traditional traps: an evaluation based on multi-species analysis

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In Maluku, Indonesia, trap fishing is one of the traditional fisheries that play an important role in supplying reef fish to sea food restaurants and to the trade of live fish. To support the sustainability of the trap fishery, it is important to analyse the catch through a multi-species approach rather than a single-species (selectivity) approach. In this study, multi-species catch analyses estimated species diversity, trophic levels and spatial distribution based on catch data, and sustainability of catch based on biological and ecological information. Traps were fished from February 2009 to January 2010 in waters 5 to 40 m deep in Ambon Bay, Waai Bay and at Babar Island. The most abundant fishes caught were the family Mullidae, *Parupeneus barberinus* (n = 171) and *P. indicus* (n = 99). Spatial distribution of species analysed with Multivariate Principle Component Analysis showed each fishing ground has significant co-varying species. Trapability of different species ranged from 20% to 67%. The mean trophic level of the traps was 3.37 (SD: 0.175), indicating that the trap catches were dominated by low to moderate levels of carnivorous secondary consumers. From 39 species captured by traps, the least likely to be sustainable was *Heniochus cuminatus*, and the most likely to be sustainable were *Carangoides* sp., *Conger* sp., and *Pseudobalistes flavimarginatus*. It is proposed that traditional trapping is a suitable practice in coral reef areas, with low impacts on the community of reef fish.

13E Fisheries
Wednesday 11 July, 1500, Hall A

Spillover of naivety to fishing across marine reserve boundaries

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How close can a spear-fisher approach a fish before it flees? This is termed flight initiation distance (FID), and has implications for vulnerability of fishes to spear gun fishing; how fishing directly impacts upon fish behaviour; a

fisherman's potential yields; and the capacity for overexploitation. We present data on fish FID across the boundaries of three no-take marine reserves and three control areas in the Philippines for two fishery target families (Acanthuridae and Scaridae), and one non-target family (Chaetodontidae). We tested six different statistical models that potentially describe how FID may vary across the boundary: linear, logistic, exponential, saturation, asymptotic and piecewise linear, and show that there is a significant linear relationship between distance from the boundary of no-take areas and fish FID for both Acanthuridae and Scaridae. FID for both these families increased on average by approximately 155 cm from 200 m inside to 200 m outside no-take areas. No significant relationship between FID and distance from the boundary was found for Acanthuridae or Scaridae at any control area, nor was a significant relationship found for the non-target family, Chaetodontidae, at any area. These results suggest that the previously undocumented mechanism of changes in fish behaviour across reserve boundaries play a role in the export of benefits from inside no-take reserves to adjacent fished reefs. However, we may also question some of the previous interpretations of increased catch per unit effort at reserve boundaries, where the benefits may be due to spillover of naïve behaviour, rather than fish abundance.

13E Fisheries
Wednesday 11 July,0945, Hall A

Ecosystem-based fisheries management: optimizing for multiple species and multiple values

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Ecosystem-based fishery management is promoted as a means of alleviating many of the escalating direct and indirect effects of fishing on targeted populations, trophic connectivity, essential habitats, and ecosystem functions. Although the ecosystem-based approach that advocates for the consideration of multiple species and values has international and growing support, few studies have tried to quantify the context-specific gains from implementing it. Using a multi-species bioeconomic model for a Caribbean reef community, we evaluate a range of management options along a continuum from open access to economically optimal management of multiple interacting species with fishing and nonfishing values. We ask: (1) Where are the largest economic and ecological gains in the progression from open access to single- and multi-species management, and how does the strength of trophic coupling influence these gains? (2) How do standing stock, fishing effort, and economic returns qualitatively and quantitatively differ as the scope of management changes? and (3) How does the explicit incorporation of nonfishing values alter management recommendations? We find that the optimal solution when accounting for nonfishing values can include temporary or permanent fishing moratoriums, in contrast to continuous fishing at low levels when only fishing profits are considered. We also show that the greatest gains from ecosystem-based fishery management are not from improved estimation of the trophic coupling, but from reforming the social and economic management of individual fish stocks and by explicitly incorporating a broader set of values into management decisions.

13E Fisheries
Wednesday 11 July, 1515, Hall A

Multidisciplinary approach to fish extirpations in global epicentre of shorefish biodiversity

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The Philippines is considered to be the global epicentre of shorefish biodiversity. Likewise, it is one of the most threatened by anthropogenic activities. Philippine marine fisheries landings are declining but the trajectories of even the most vulnerable species are scarcely known. Which species are being lost and where, and reference points for possible future recovery, are unclear. Fish extirpations (i.e. local extinctions) have been detected in a pilot study in Bohol, Central Philippines: giant grouper *Epinephelus lanceolatus* (IUCN vulnerable status, but not protected in the country) and pompano *Alectis ciliaris* (not evaluated by IUCN, unprotected in the country). Also, temporal abundance trends of 10-13 reef fish families showed significant decline according to linear mixed models based on fishers' knowledge (1950-2007) and underwater visual census (1985-2007). Meanwhile, more than 50% of selected major target fish species in Camotes Sea and Davao Gulf significantly declined from 1985-2005 based on landings data. These local extinctions and declines were attributed to both life history vulnerabilities and overexploitation. The pilot study using a multidisciplinary approach, can be potentially rolled over to key marine biodiversity areas in the country to test its wider implications at

various scales. Further, strengthening of capacity in local resource management e.g. policy advocacy and training, can be done at the pilot site. Lessons pooled from the site conservation actions and threatened species work can potentially be used to advocate for protection and national recognition of threats by the Philippines National Biodiversity Action Plan, Philippine government agencies and IUCN (World Conservation Union) Red List Authority.

13E Fisheries
Wednesday 11 July, 1030, Hall A

Critical ecological switch points and reef fisheries degradation and recovery

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Sustainably managing ecosystems is challenging, especially for complex ecosystems such as coral reefs. A large empirical data set on the coral reefs of the western Indian Ocean found eight metrics of ecosystem state that exhibited specific switch points along a continuum of fishable biomass, ranging from heavily fished sites to old fisheries closures. Three switch points lay above and five points below a hypothesized window of fishable biomass expected to produce a maximum multispecies sustainable yield. Recovery rates after each of these switch points is likely to differ, as the number of ecological barriers and associated equilibriums can prevent a simple return to a previous undisturbed state. For example, high levels of erect algae and sea urchins and low levels of coral create negative feedbacks and barriers to rapid recovery of fish populations based on aspects of fish feeding, recruitment, and growth rates alone. I present estimates of recovery from Kenyan reefs that passed seven of the eight switch-points attributable to heavy fishing and find highly variable responses among the fish, which are not well predicted by their feeding but better by growth and mortality metrics. Recovering reefs were changing towards lower human disturbance even after 40 years of closure from fishing.The time to recover can be long and could increase further when human disturbances increase in the surrounding seascape, and create spatial and functional group bottlenecks to recovery. In particular recovery of herbivorous fishes was slow and creates challenges for recovery and reef resilience to climate change.

13E Fisheries
Wednesday 11 July, 1115, Hall A

Marine Protected Areas effectiveness on reef fish assemblages; Cayman Islands

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Reef studies in the Cayman Islands have focused on coral communities; few studies have been carried out on fish assemblages. There is no active commercial fishery but recreational fishing pressure is significant. Marine Protected Areas (MPAs) were established in 1986 to protect coral reefs and their associated organisms, whilst maintaining fish stocks, and replenishment of fish to surrounding areas. Important fish species for reef health function and species most commonly targeted by fishers, have been compared between enforced no-take areas and unprotected areas. A fish census of 53 target species representing the different trophic groups was carried out by Underwater Visual Census (UVC) around Grand Cayman, Cayman Brac and Little Cayman between January and April to assess biomass, size and density, including the relationship between the different trophic groups. The exportation of individuals by spillover effects was measured over a 5 km distance from each boundary using linear regression of the mean biomass per site. Reserve effect, evaluated for the first time after 25 years of protection was significant in Grand Cayman ($p<0.01$). Cayman Brac showed no reserve effect; and the MPAs of Little Cayman demonstrated a reserve effect in the southern MPA only ($p<0.01$). A spillover effect was only evident on the north boundary of the MPA in Grand Cayman ($R=0.9158$, $p< 0.01$). The results suggest that some MPAs have been more successful than others; this knowledge is being used to enhance Cayman MPAs to make them fit for purpose for the next 25 years.

13E Fisheries
Wednesday 11 July, 1035, Hall A

Do no-take reserves accumulate older age-classes of heavily exploited parrotfish species?

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A detailed demographic study was employed to test the assumption that Marine Preserves in the southern Mariana Islands enable a build-up

of older age classes for two common parrotfish. Underwater visual census of the entire parrotfish assemblage supplemented the demographic data providing valuable insights into the spatial composition of these and other parrotfish species on Guam and neighbouring islands. Otolith analysis confirmed that *C.sordidus* and *S. psitticus* are short lived with a maximum age of 9 yrs and rapid initial growth. Sampling inside and outside of Guam's Marine Preserves revealed strong fishing effects. Mean longevity and body size varied considerably with different rates of fishing mortality. Size at sex change for *C. sordidus* and three other parrotfish species differed with increasing fishing pressure across the Marianas. Multivariate analysis of the census data indicated 'exposure' and 'fishing intensity' were the most influential variables structuring parrotfish assemblages. Biological interactions were also significant; sites where the territorial acanthurid *Acanthurus lineatus* were low due to excess fishing saw an increase in small bodied parrotfish. Management regime had no apparent influence on assemblage structure with sites open and closed to fishing clustering together in multivariate space. Long-term catch and effort data revealed *C.sordidus* and other short-lived species have undergone little or no significant change in mean body size over 25 years despite a dramatic increase in fishing pressure. Conversely, parrotfish with greater longevities (tmax>10 yrs; e.g. *Scarus altipinnis*, *Cetoscarus bicolor*) suffered a significant decline in body size over the same time period.

13E Fisheries
Wednesday 11 July, 1400, Hall A

Status, trend and sustainability of small-scale fisheries in the Philippines

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Implementing management initiatives aimed at promoting recovery of depleted fisheries in the Philippines proved to be challenging in the face of poor fishery-dependent fishing communities. Harmonizing the varied options between resource protection, sustainable use, and welfare of the fishers needs to be considered in fisheries governance. An assessment of coastal fisheries of 25 coastal towns in the Philippines using FISHDA (Fishing Industries' Support in Handling Decisions Application) model was done to afford general rules to be considered in management to be within its fishing capacity. Results showed that the fisheries in 64% (16 out of 25) of the towns are unsustainable. To prevent fishery collapse, those towns need to either protect 56% of their fishing grounds or reduce the number of active fishers by 55%. When 15% of the fishing grounds were protected, as mandated by the law, only 3 of the previously unsustainable fisheries became sustainable. Further, the number of fishers that can be supported slightly improved by 5%. Currently, the average MPA size in all towns is only around 4.5% of the municipal waters with only El Nido and Masinloc exceeding the mandated 15% MPA size. Our findings demonstrated that increasing MPA size, according to the recommendation of the law, will not be enough to avert fishery collapse if not complemented with other measures that reduce dependency on the fisheries. Important recommendations to improve the condition of fisheries based on the ecological and socio-economic attributes of the towns are further discussed.

13E Fisheries
Wednesday 11 July, 1230, Hall A

Incorporating visual surveys into population assessments of Hawaiian reef fishes

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The NOAA Pacific Islands Fisheries Science Center (PIFSC) conducts ecosystem-wide surveys of coral reef fish populations and benthic habitats around the Hawaiian Islands using non-destructive underwater visual census methods. Recent implementation of a stratified random sampling design for fish surveys has raised the possibility of using spatially explicit, size-structured abundance data for population assessments by combining these data with life history information into length-based mortality assessment and population dynamics models. We will present examples that demonstrate how these design-based population estimates can be incorporated into population assessments for several reef fish species in the Hawaiian Islands. We will also present new tools to incorporate model parameter uncertainty into these analyses, and to provide more robust life history parameters for species lacking detailed growth and age-at-maturity information.

13E Fisheries
Wednesday 11 July, 1015, Hall A

Management of the Grouper fishery of the Maldives

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The Grouper (family Serranidae, Subfamily Epinephelinae) Fishery in the Maldives has reached a crucial stage in its exploitation, where management is not simply an issue of something that is required for the fishery, but something, which at this stage is critically needed. The market oriented Grouper Fishery in the Maldives which started in the early 1990s, soon escalated, spreading throughout the Maldives, with the export market (live and fresh chilled exports) being the sole source of demand. The lack of management of this fishery has resulted in an unsustainable fishery showing a declining trend. Live exports (high value) are on a continual decline. Decrease in size, a classic sign of over-fishing, is observed for the commonly exploited species. The majority (69%) of the individuals belonging to the ten most in-demand species are currently being caught prior to them reaching their theoretical maturity lengths. These include the high valued species such as those belonging to the *Epinephelus* genus, *P. laevis* and *P. pessuliferus*, which are exported live in large numbers. Recent work to manage the fishery started with the formulation of a management plan through a participatory approach. Measures such as size limits on catch and exports, spawning area closures and export quotas have been recommended, and are being put forward to policy makers for their endorsement and implementation. Strengthened data recording and reporting systems, monitoring and enforcement are also incorporated for efficient implementation of the management plan.

13E Fisheries
P130

Decadal change in fish community structure within a Caribbean MPA

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Documenting the long-term effects of marine protected areas (MPAs) has been challenging due to a general lack of early data on the composition of reef fish communities inside and outside no-take areas. While we are starting to gain a strong appreciation for the effects of MPA zoning on high-diversity coral reef ecosystems within the Indo-Pacific (e.g. Philippines, Great Barrier Reef), we have a relatively poor understanding of the impact of MPA zoning on comparatively low-diversity Caribbean coral reef fish communities. Here we build upon an early study (1991-1995) of the Saba Marine Park (MP) and provide an update on how the composition, abundance and biomass of target and non-target reef fish species have changed across take and no-take zones over the two-and-half decades since the Saba MP was established in 1987. We explored the contrasting roles that natural variation and fishing pressure play in shaping change within the Saba MP reef fish community, and how trends within this low-diversity system compare with those found in long-term studies of similarly small-scale MPAs established on Philippine coral reefs.

13E Fisheries
P131

Assessing management scenarios: a spatially-explicit approach for *Plectropomus leopardus* in New-Caledonia

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Spatial heterogeneity of large coral reef ecosystems makes populations dynamics and fisheries dynamics highly complex. Non-spatialised models are unsuccessful in describing connectivity phenomena in exploited populations and fragmentation of fishing effort. New-Caledonian South-West lagoon is a large enclosed lagoon (3485 km²) with many reef structures, and constitutes an interesting case study. This area faces fishing pressure from both recreational and professional fishers. As one of the most targeted species, *Plectropomus leopardus*, is highly impacted by these activities. In this work, we propose to assess 1) the actual management plan, based on a MPA network, and 2) alternative scenarios (MPA, gear restriction, TAC, license, etc.). We first built a spatially-explicit model including both *P. leopardus* population dynamics and fisheries dynamics. Then we assessed uncertainty through sensitivity analysis, and discussed simulations of management scenarios under uncertainty. Results show that connectivity, larval dispersion, and recruitment are key issues affecting uncertainty regarding efficiency of management measures, however,

management measures respond differently to uncertainty.

13E Fisheries
Wednesday 11 July, 1245, Hall A

Where the wild things are: large-bodied coral reef fishes

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Large-bodied reef fishes are economically and ecologically important, often supplying the bulk of the reproductive output for their population and having a disproportionate effect on their environment. These fishes also tend to be at greatest risk of overfishing. While many studies have investigated environmental factors affecting populations of small-bodied reef fishes, few have explored these relationships with respect to large-bodied species. The present study describes the distribution of large-bodied reef fishes in the Mariana Archipelago and Northwestern Hawaiian Islands with an emphasis on environmental correlates. Among eighteen environmental variables, a negative association with human population density was the predominant factor affecting the distribution of large-bodied reef fishes. Large-scale environmental factors including depth, water temperature, and distance to deep water were also important. In contrast to previous studies showing the importance to small-bodied reef fishes, of small-scale factors such as rugosity and benthic cover, these small-scale factors were of lesser importance to large-bodied fishes. This suggests that the fish-habitat relationship is scale dependent and that models based on small-bodied species may not be applicable to larger-bodied species. Our results also suggest that the relationship between large-bodied fishes and human population density is primarily driven by fishing and not by habitat degradation, as anthropogenic habitat degradation typically affects the small-scale factors we found to be of lesser importance. These findings add to our understanding of the ecology of large-bodied reef fishes and can inform discussions of essential fish habitat, marine protected area design, and ecosystem-based management.

13E Fisheries
Wednesday 11 July, 1715, Hall A

Management options for a traditional humphead wrasse fishery in Fiji

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The instantly-recognizable humphead wrasse (*Cheilinus undulatus*) is of considerable traditional customary significance in many Pacific islands. Listed as endangered by IUCN, the species is particularly vulnerable to overexploitation because of its life-history characteristics, and notable population declines have been recorded at sites where fishing pressure is only of a moderate level. However, few long-term studies have been conducted, possibly because of the generally illicit nature of these fisheries and often-ineffective monitoring and management policies. We have worked closely with a remote Fijian community living on the Great Sea Reef that almost exclusively relies on coral reef fisheries for their subsistence and livelihood needs. The fishers of the community are the appointed traditional fishers for the provincial chief and are responsible for a substantial, long-enduring (and now illegal) *C. undulatus* fishery, with individuals spearfished on an almost daily basis at various life history stages. Interestingly, although *C. undulatus* is a highly valued live reef food fish, the fish caught at our study site were destined mainly for local consumption and were not of higher monetary value per kg than other reef fish species. We discuss daily landing site, fishing grounds and socioeconomic data and present information on stock management, spawning aggregations, traditional knowledge, management efforts and historical perspectives. We suggest management actions that may contribute to the sustainability of the fishery in the face of increasing demand and access to market.

13E Fisheries
Wednesday 11 July, 1730, Hall A

Impact of climate change on reef fish fisheries at Sabang Aceh

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Aceh is one of the provinces with the largest coastal region in Sumatra, Indonesia. Around 25% of Acehnese are dependent on coastal ecosystems, mainly in the fisheries sector. However, mass coral bleaching was observed at Sabang, Aceh in early 2010, and approximately 80% of hard coral in waters surrounding Sabang died post-event. Coral mortality was expected to affect the composition of reef fish due to elimination of a number of coral functional roles, such as providing a home, a place to eat, shelter and as

breeding grounds for fish and other marine organisms. The objective of this research was to compare the coral reef fish catches in Sabang waters before and after the coral bleaching. The data were collected before (in 2008) and after (in 2010) the mass coral bleaching event in Acehnese waters by using a photographic method. Analysis of data on the average catch of fishermen was calculated in units of catch per fishing effort (kg/hour). The results showed that 259 species of coral reef fishes were caught by fishermen in 2008 and 2010. There was no significantly difference between the fish catches before and after the 2010 coral bleaching. However, species richness decreased by around 50% after the coral bleaching. The knowledge of fishermen in how they might adapt to climate change, was very low. Consequently, there is a need to educate the fishermen in Sabang Aceh about climate change issues in order to build their capacity to adapt.

13E Fisheries
Wednesday 11 July, 1215, Hall A

Managing coral reef fisheries under catch limits: approach and challenges

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The Reauthorization of the Magnuson-Stevens Act in 2006 had significantly changed the way Regional Fishery Management Councils deal with managing the US fisheries through implementation of annual catch limits (ACLs). Stock and output control-based approaches like ACLs pose problems for fisheries that are multi-gear, multi-species and spatially diverse by nature. The National Standard 1 Guidelines of the National Marine Fisheries Service is reliant on the existence of Maximum Sustainable Yield (MSY) for stock managed under ACLs. This provides very little guidance for reef fishes that has very few stock assessments on which the overfishing limit, a critical component of the ACL process, is based upon. Biological reference points that determine stock status are lacking for most of the species. Managing stocks that are data deficient proved to be a big challenge. This presentation outlines the approach that the Western Pacific Regional Fishery Management Council took in specifying ACLs for reef fishes in the US Pacific state and territories. Gaps and challenges were identified and recommendations are provided to enhance management of stocks under a catch limit system.

13E Fisheries
Wednesday 11 July, 1545, Hall A

Investigating spillover for a marine protected area in Hawaii

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Marine protected areas (MPAs) are widely utilized as a management tool to conserve biodiversity and to protect and restore fish populations within their borders. MPAs benefit fisheries through two primary mechanisms: increased production via export of pelagic eggs and larvae, and the net emigration of adults and juveniles (spillover). Spillover was investigated for a marine reserve on the north shore of Oahu in the Hawaiian Islands. Originally designated in 1983, community efforts led to its expansion in 2003 resulting in the current area of 71.0 ha. To test the spillover hypothesis, a seascape approach was utilized incorporating habitat variables at multiple scales as well as observed patterns of fishing effort. Underwater visual surveys for fish and benthos were conducted inside and outside the reserve at varying distances from the boundary. The relationship between fish biomass and key habitat variables (depth and structural complexity) was found to account for a large portion of the variability for both resource (targeted) fish species (27%) and non-resource fish (33%). The remaining variation in resource fish biomass was significantly correlated ($p<0.001$) with distance from reserve boundary, showing a decreasing gradient from inside to outside ($r^2=0.43$), indicating fish spillover at a local scale (<1 km). In contrast, non-resource fish biomass demonstrated no such relationship ($p=0.12$). These findings were supported by fishing effort patterns which showed high intensity in the open area adjacent to the reserve boundary and declined with distance.

13E Fisheries
Wednesday 11 July, 1415, Hall A

Revisiting the source of carbon fueling fisheries on coral reefs

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Quantifying carbon flows on coral reefs is fundamental to the development of models capable of predicting the response of reef ecosystems to threats including overfishing and global climate change. For instance, it is often assumed that water column-based

phytoplankton production is the dominant carbon source fueling large predatory fish, such as snapper and grouper, on coral reefs. However, recycled carbon passing through microbial pathways may also supply significant amount of carbon to high trophic levels. We addressed the relative contribution of new versus recycled carbon in coral reef food webs using stable carbon isotope ($\delta^{13}C$) analysis of specific amino acids from samples collected on reefs along a cross-shelf gradient in the northern Farasan Banks, Kingdom of Saudi Arabia. Microbial reworking of C imparts a distinctive $\delta^{13}C$ signature in essential amino acids that is distinctive from that of C fixed by phytoplankton, and this signature propagates up food webs without any trophic fractionation. Our results highlight the remarkable complexity of food webs on coral reefs. For instance, two congeneric snapper species in the Red Sea (*Lutjanus kasmira* and *L. ehrenbergii*) commonly occur together in mixed species schools on reefs across the shelf and yet are isotopically completely distinct. While *L. kasmira* apparently feeds on C derived from phytoplankton, *L. ehrenbergii* relies almost entirely on C that has been recycled through a detritivore pathway. Compound-specific stable isotope analyses represent a powerful new tool for tracking movements of fish through isoscapes and for tracing the origin of nutrients fueling reef ecosystems.

13E Fisheries
Wednesday 11 July, 1430, Hall A

Impacts of recreational and artisanal fisheries, Cayman Islands, Caribbean

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To examine the potential impact of recreational and artisanal fisheries on reef ecosystems in the Cayman Islands (where there is no commercial fishing), the level of fishing pressure was investigated by using structured questionnaires directed at fishers. Illegal fishing pressure was investigated using marine enforcement officer reports spanning 1993-2010. Within a monthly period, fishers reported catching 14,968 fish on Grand Cayman and 5205 fish on the Sister Islands (88% and 80% of which were reef fish, respectively). The mean catch size was 72 (±SD 152) fish $month^{-1}$ on Grand Cayman, and catch size was significantly higher for respondents targeting reef fish than for those targeting pelagic species (Mann-Whitney U test, $P<0.01$). The mean number of days spent fishing $month^{-1}$ ranged between 5.1 (±SD 6.5) and 8.4 (±SD 7.4). While Lutjanids were caught in greatest numbers, of greatest concern were the numbers of herbivores extracted. Fishing effort was non-uniformly distributed around the islands (Chi-square tests, $P<0.01$) being aligned closely with fringe reefs, populated areas and shore access points. Poaching in the MPAs and other illegal fishing activities remain an issue, with the queen conch (*Strombus gigas*) representing the major target organism. Despite major support for the idea of marine environmental management, over 50% of interviewed fishers believed that enforcement of marine park laws is currently inadequate. The impacts of artisanal and recreational fishing is often overlooked; this study indicates that both practices are significant in the Cayman Islands, with the potential to influence reef resilience and ecosystem functioning.

13E Fisheries
Wednesday 11 July, 1000, Hall A

Socotra Archipelago: unique fish diversity meets exceptional productivity

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The Socotra Archipelago hosts diverse and biogeographically unique fish communities. About 735 coastal and pelagic species in 109 families have been recorded, and over 850 species are expected to occur. The islands are endowed with the highest diversity of marine fishes in the Arabian region. Strikingly, certain 'reef' associated families and functional groups are as diverse, or even more diverse, than their respective groups in the entire Red Sea, even though the islands' total coastline is approximately eight times less in length and supports considerably fewer biogenic reefs. The impressive fish diversity is matched by the high productivity. Inshore fish biomass estimates were started in 2007 as a proxy of coastal productivity, adding to the permanent transect-based monitoring programme and fisheries data collection system set up in 2000. Estimates of standing crop in 2007 (pre-monsoon) averaged 2.08 t/ha across eight sites and 3.04 t/ha at five deeper sites (> 6m), with maxima in excess of 5 t/ha at one site at Socotra Island and one at Darsa Island. These values surpass biomass estimates of long-term no-take reserves in the Western Indian Ocean, even though most sites at Socotra must be considered fished, despite the existing MPA system and network of traditional no-take zones. Fish biomass data of 2011, however,

indicates a sharp decline in standing crop. Spatio-temporal trends in fish community composition are discussed in relation to critical functional groups of fish, benthic community dynamics, and the impact of what was formerly dubbed a sustainable shore-based fishery.

13E Fisheries
Wednesday 11 July, 1700, Hall A

Quantifying the unreported fisheries catch of all Pacific island countries in the larger Pacific Basin

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Fisheries in the tropical Pacific are important economically, culturally and for food security, yet government focuses often on large-scale tuna fisheries only. This one-sidedness undervalues small-scale fisheries, both politically and socio-economically. We present the results of 10 years of research on reconstructing fisheries catch time series from 1950-present for over 20 island countries and territories in the Pacific basin. Our approach develops estimates of total catch using all available information sources, combined with assumption-based expansions and interpolations. Under-reporting to FAO ranged from a low of 40% to the more typical 2-3 fold, but went as high as 7 fold. The discrepancy in national and hence global statistics is primarily driven by the chronic under-representation of both commercial and non-commercial small-scale fisheries in national statistics. While yearly estimates for widely dispersed small-scale fisheries are expensive to obtain, and are the prime reason for incomplete catch accounting by many counties, these fisheries are of fundamental importance to food security, especially under increasing stresses due to climate change and non-fisheries anthropogenic influences. It is suggested that regular, non-annual, country-wide estimates of total catches should be undertaken as a priority activity by all countries, interpolated for intervening years, to provide a firmer basis for the official national data. Such data collection can be incorporated cost-effectively in existing national census and household survey approaches. Due to financial and human resource limitations in many of the Pacific Island countries, this requires facilitation and support from regional agencies, such as the Secretariat of the Pacific Community (SPC).

13E Fisheries
Wednesday 11 July, 1445, Hall A

Theme 14. Larval ecology, recruitment & connectivity

14A The ecological importance of larval dispersal

Retention of larvae in a reef mosaic

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Waters in areas of high reef density are poorly renewed because the currents are steered around and away from these regions. This process is defined as the 'sticky water' effect. We have applied a high resolution finite difference grid to study the circulation around different reef structures. The results showed that the sticky water effect leads to a high flushing time in high reef density areas in the southern (e.g. Swain Reefs) and central regions of the Great Barrier Reef matrix. In turn this generated hotspots of high self-seeding, and these hotspots existed under both calm weather conditions and wind conditions typical of those during the coral spawning season and that of many fishes. Differently, in low reef density areas, self-seeding was less likely to occur and larval replenishment would result mainly from connectivity between reefs located kilometers to tens of kilometers apart. Sticky water areas varied spatially within the reef matrix according to tidal and mean currents, local bathymetry and reef density and a simple formula is presented that explains over 65% of the variation in larval retention in both calm weather and windy conditions. Another simpler formula is proposed based on the bathymetry only that explained 67% and 52% of the variation in larval retention in calm weather and under windy conditions respectively.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1200, Hall C

Larger female fish contribute more to self-replenishment

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It is widely accepted that the stochastic nature of replenishment in marine populations is due to oceanography, selective pressures and chance events. A certain degree of determinism in the replenishment of marine populations may however be warranted by the characteristics of individual breeders. It is well known that larger females have higher fecundity and recent laboratory studies have shown that maternal traits such as age and size are positively associated to offspring growth, size and survival. Contrary to laboratory evidence, a myriad of putative natural sources of selection may hinder a clear relation between maternal characteristics and population replenishment in the wild. Whether maternal size translates into higher recruitment in natural populations remains unanswered. We studied a natural population of *Amphiprion chrysopterus* in Moorea (French Polynesia) over two years to test whether maternal size translated into higher self-recruitment. We sampled 378 individuals on the island and through parentage analysis identified 27 self-recruits out of 101 sampled recruits. We also identified the location of females that produced the self-recruits, and taking into account the variation of maternal size among sites we found that females producing self-recruits were significantly larger than those that did not. We show for the first time in a natural population that larger female fish have an elevated contribution to local replenishment (self-recruitment) and discuss the implications for fisheries management and conservation.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1630, Hall C

Larval dispersal patterns within an MPA network in Kimbe Bay

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The use of marine protected area (MPA) networks to sustain fisheries and conserve biodiversity is predicated on two critical yet rarely tested assumptions. Individual MPAs must produce sufficient larvae that settle within that reserve's boundaries to maintain local populations while simultaneously supplying larvae to other MPA nodes in the network that might otherwise suffer local extinction. Here, we use genetic parentage analysis to investigate patterns of local replenishment of two reef fishes (a benthic spawner, *Amphiprion percula*, and a pelagic spawner, *Chaetodon vagabundus*) in an MPA in Kimbe Bay, Papua

New Guinea over several years. Successful settlement of larvae on their natal reef ('self-recruitment') appears to be relatively high at our study sites, typically 40-60%. Inter-annual assessment of the dispersal patterns reveals several important details. First, the patterns of dispersal varied greatly through time. Second, when simultaneously comparing dispersal of our two study species, the patterns differed, suggesting that biology and/or behavior of the species plays an important role in realized dispersal patterns. Finally, self-recruitment in this system appears to be a persistent trait in our study populations and recurs at a demographically significant level. The stability of our estimates of local replenishment suggests that even small MPAs may be self-sustaining. However, our results caution against applying optimization strategies to MPA network design without accounting for variable connectivity among species and over time.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1515, Hall C

Probability of successful larval dispersal declines fivefold over one kilometer

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A central question of marine ecology is, how far do larvae disperse? High-resolution biophysical models predict that the probability of successful dispersal declines as a function of distance between populations. Estimates of genetic isolation-by-distance and self-recruitment provide indirect support for this prediction. Here, we conduct the first direct test of this prediction, using data from the well-studied system of clown anemonefish, *Amphiprion percula*, at Kimbe Island, in Papua New Guinea. *A. percula* live in small breeding groups that inhabit sea anemones. These groups can be thought of as populations within a metapopulation. We use the x and y coordinates of each anemone to determine the expected distribution of dispersal distances (the distribution of distances between each and every anemone in the metapopulation). We use parentage analyses to trace recruits back to parents and determine the observed distribution of dispersal distances. Then, we employ a logistic model to i) compare the observed and expected dispersal distance distributions and ii) determine the relationship between the probability of successful dispersal and the distance between populations. The observed and expected dispersal distance distributions are significantly different ($P<0.0001$). Remarkably, the probability of successful dispersal between populations decreases fivefold over one kilometer. This study provides a framework within which biological and physical hypotheses for the factors influencing marine larval dispersal may be tested in unison, which will advance our understanding of population connectivity.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1500, Hall C

Effect of reef eddies and swimming behaviour on larval recruitment

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Reef fish larval dispersal is commonly quantified using biophysical models that simulate circulation and include behaviour. Due to computational constrains, the great majority parameterize reef-scale turbulence, rather than modelling such features explicitly. Also, most models assume that larvae are passive initially, and start navigating constantly towards the nearest reef once they reach the post-flexion stage. Here, we developed a 3D hydrodynamic model with reef-scale spatial resolution for section of the Central Great Barrier Reef encompassing 20 reefs, which allows us to explicitly resolve the dynamics of eddies in the lee of reefs. In addition, we use empirical data to calibrate sub-models for the development of swimming ability as fish age, and we explore the extent to which different behavioural strategies for exploiting lee reef eddies can influence energy expenditure, and the retention or dispersal of larvae. We find that the potential for lee reef eddies to promote self-recruitment is more limited than previously thought, regardless of behavioural strategy. In addition, the success of larval strategies for enhancing recruitment by exploiting lee reef eddies later in larval life is highly sensitive to both energetic considerations, and to the detailed dynamics of eddy formation and shedding in the lee of reefs. These results highlight the importance of considering larval behavioural strategies, and the dynamics of lee reef eddies for understanding patterns of retention and dispersal on coral reefs.

14A The ecological importance of larval dispersal
Wednesday 11 July, 0945, Hall C

Pathways of connectivity amongst West Caribbean Spiny Lobster stocks

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The long larval period of spiny lobster may be a factor influencing the connectivity of stocks, where larvae may drift with the currents. We hypothetized that some evidence of this could be found by examining the age structure of the stocks exploited in the west Caribbean countries where sea current pathways move from south to north. Age structure of stocks from ten countries exploiting spiny lobster was used to test connectivity links. Fifteen years of catch data were obtained from the FAO statistical records and were transformed into numbers per age class throughout these years by using population parameter values and simulation. The possible correlation between each of the one year-old recruits numbers in pairs of countries was tested and loose correlations were found in most cases (r^2=0.4-0.5). The R^2 value of total number of recruits was 0.7-0.8 with Florida, 0.8-0.9 with three countries, and >0.9 with Mexico, Honduras and Haiti. Next, correlations of the number of recruits with all the stock number one year later in eight countries were examined. Significant correlations (r^2>0.5) were found in eight countries; however, a strong correlation (r^2>0.9) was found in 13 combinations, and somewhat lower (r^2=0.8-0.9) in eight others. We conclude that the connectivity is strong among Cuba, Mexico, Florida, Belize, Honduras, and Colombia, reinforcing the recommendation that the spiny lobster fisheries should be managed by an international entity.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1215, Hall C

Connecting Kimbe Bay reef fish dispersal with regional circulation

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Understanding the degree of connectivity among coral reef meta-populations is central to our understanding of the functioning of the reef ecosystems, and a fundamental requirement for the effective designs of marine protected areas. To date, our understanding of how reef fish populations are connected through larval dispersal has been advanced by a number of field tagging and genetic studies, which hint at variable levels of self-recruitment and input from distance sources. Yet while regional circulation likely plays an important role in larval dispersal, *in situ* measurements of both larval connectivity and hydrodynamics in the same area are rare. Here we combine a field study measuring connectivity among populations of two coral reef fishes (*Amphiprion percula* and *Chaetodon vagabundus*) using DNA parentage analysis with a state-of-the-art coupled biophysical model to assess the role played by the regional circulation in determining connectivity patterns. An unstructured grid model - the Finite Volume Coastal Ocean Model (FVCOM) - was used to model current regimes and an embedded particle tracking module provided dispersal pathways of virtual reef fish larvae with simplistic behaviour and spatially invariant mortality. The model was calibrated and validated using *in situ* measurements of temperature, salinity, velocity and sea surface elevation. The results allowed us to provide a first order approximation of the degree to which current flow mediates realized dispersal distance in coral reef fish.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1500, Hall C

Modelling and visualisation of connectivity on the Great Barrier Reef

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Connectivity between reefs has been identified as a major determinant of resilience in coral reef systems. Conversely, connectivity to onshore and offshore human activities can pose major threats to reef systems. While realized patterns of biological connectivity are difficult to infer, a complimentary approach is to predict likely dispersal from an understanding of oceanographic currents and the swimming behaviours of organisms. We have developed an online tool CONNIE (www.csiro.com/connie2/) that allows users to rapidly estimate connectivity between reefs and exposure of reefs to coastal inputs. It uses ocean currents generated by a high-resolution three-dimensional hydrodynamic model

covering the entire Great Barrier Reef (GBR) region. The underlying particle tracking techniques allow a wide range of biological behaviours to be specified including vertical migration, horizontal swimming and surface slick formation. Progress on coupling CONNIE to ecosystem models (Atlantis) and reserve design tools (MARXAN) will also be described.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1245, Hall C

Larval connectivity assessed with biophysical modelling and otolith transgenerational marking

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Studying connectivity among reef ecosystems through larval dispersal is essential for answering many management and scientific questions, such as achieving effective spatial management of reef resources (e.g., marine protected areas) and understanding the spatial structuring of marine ecosystems. However there is a significant gap between the ability to experimentally measure connectivity and the ability to model larval transport. We studied larval transport and population connectivity of a damselfish (*Dascyllus aruanus*) in the South Lagoon of New Caledonia (SLNC) using two emerging and complementary approaches: microchemical analysis of artificial markers and a biophysical model of larval transport. We used the technique of transgenerational marking of embryonic otoliths in a small focal reef population of *D. aruanus* by injecting an enriched ^{137}Ba isotope solution in the abdominal cavity of gravid females. Recruitment of these larvae was followed over time to determine the self-recruitment rate back to the focal reef, as well as larval export to ten neighboring habitat patches. Parallel to this experimental analysis, we developed a biophysical model of damselfish dispersal based on passive transport in a three-dimensional dynamic ocean currents model. Discrepancies between experimental and simulated connectivity patterns indicate the need for integrating larval behavior, such as diurnal vertical migrations, in the dispersal model.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1415, Hall C

Coral genetic connectivity across Micronesia

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Understanding coral larval dispersal is imperative to predicting population level responses to climate change. Few studies have looked into the connectivity among reefs in Micronesia and to date, no data on coral genetic exchange have been published for this broad area of the Pacific. Knowledge of the source-sink dynamics between these remote reefs is especially important since they occur as discrete stepping-stones across large expanses, and the extinction of individual populations may have far-reaching demographic effects. Micronesian reefs, therefore, offer a unique opportunity to test evolutionary theories and apply these to conservation planning. We analyzed twelve microsatellite loci across nearly 2000 individuals to determine the connectivity patterns and distribution of genetic diversity in two species of reef-building corals (*Acropora hyacinthus* and *A. digitifera*) in Micronesia across different spatial scales, with samples from 22 reef sites across 9 island groups. Due to the west to east equatorial Pacific Ocean currents, we hypothesized that genotypic diversity would decrease from west to east across Palau, the Caroline Islands and into the Marshall Islands, and that migration direction would also be predominantly west to east. Our preliminary findings support this hypothesis demonstrating a decrease in genotypic diversity from Palau east to Pohnpei. The probability of reef re-population decreases with decreasing genetic diversity. Therefore, if this trend holds, management action may be necessary, as eastern Micronesian reefs will be more susceptible to disturbance events.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1700, Hall C

Habitat protection and the recruitment of coral reef fish juveniles

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Marine protected areas (MPAs) have become a common and widely accepted intervention to address the overexploitation in the Philippines. To date, more than 1500 MPAs have been established in the country but there is limited work on its implications to recruitment. We compared the abundance and the number of species of the settling reef fish juveniles

between areas inside and outside MPAs in fifteen (15) municipalities in the country. Fish visual census and line intercept transect techniques covering a total of 124 (50m) transects were conducted from March to July 2011. Overall, there was mean abundance of 52 (±130) fish juveniles and 4.8 (±3.4) species per $50m^2$. No significant differences were observed in abundance and species richness of reef fish juveniles between areas inside and outside MPAs, only among municipalities. These suggest that the variation on a large scale could be attributed to the effectiveness of the design as well as poor implementation of some MPAs. On the other hand, hydrodynamic and other bio-physical factors could explain the difference among municipalities. Initial results on the correlation of adults and fish juveniles implicate microhabitat attributes influence overall recruitment patterns in the area. The emergent hypothesis on the benthic attributes influencing settlement behavior and recruitment of fish juveniles seems to prevail. Albeit the apparent good correlations between fishing pressure and overall adult abundance, their effects on recruitment limitation needs further investigation.

14A The ecological importance of larval dispersal
P132

The effects of global warming on patterns of connectivity in corals

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The recovery of coral populations following disturbance depends largely on larval recruits. Populations on reefs with greater levels of larval retention and/or connectivity should generally recover faster. Global warming is likely to have profound effects on patterns of connectivity because higher temperatures will hasten larval development and increase mortality. We tested the effect of temperature (24, 26, 29 and 30°C) on the rates of acquisition of competence of *Acropora tenuis* and then simulated how this would affect larval retention. The time to acquire competence was substantially reduced as temperature increased (from 81-82 h at 24-26°C to 42 h at 30°C). Using residence time estimates for six reefs from the GBR, we estimate that, as temperature increases from 26 to 30°C, the proportion of larvae retained by the natal reef will increase between 1.9-6.2%, and reduce dispersal and connectivity. Reefs with retention times similar to the larval pre-competence time will experience greater changes. In reefs where larval retention times are short, e.g. Wheeler Reef, the number of larvae that recruit back to the natal reef may increase up to 4.6 times. This suggests that, as oceans warm, coral recovery rates will depend on reef larval retention times, species specific larval competence dynamics and the scale of disturbance. Recovery from regional-scale disturbances will hasten because self-recruitment will be higher and larval loss to mortality or predation will decline. However, if disturbances are highly localized, the reduced connectivity (i.e., less recruits from undisturbed reefs) could offset the increase in self-recruitment and therefore lower recovery rates.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1445, Hall C

Do larvae always matter? The role of adult fish traits

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How do biogeographically different provinces arise in response to oceanic barriers to dispersal? Do larvae always matter for long distance dispersal? Here, we analyse how traits related to the pelagic dispersal and adult biology of 985 tropical reef fish species correlate with their establishment of populations on both sides of two Atlantic marine barriers: the Mid-Atlantic Barrier (MAB) and the Amazon-Orinoco Plume (AOP). Generalized linear mixed-effects models indicate that predictors for successful barrier crossing are the ability to raft with flotsam for the deep-water MAB, non-reef habitat usage for the freshwater and sediment-rich AOP, and large adult-size and large latitudinal-range for both barriers. Variation in larval-development mode, often thought to be broadly related to larval-dispersal potential, is not a significant predictor in either case. Many more species of greater taxonomic diversity cross the AOP than the MAB. Rafters readily cross both barriers but represent a much smaller proportion of AOP crossers than MAB crossers. Successful establishment after crossing both barriers may be facilitated by broad environmental tolerance associated with large body size and wide latitudinal-range. These results highlight the need to look beyond larval-dispersal potential and assess adult-biology traits when assessing determinants of successful movements across marine barriers.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1000, Hall C

Selection drives the genetic structure of coral reef fish populations

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The genetic structure of populations can provide information on dispersal and genetic exchange as well as on selection processes that favour survival and reproductive success of specific individuals. Over the last 9 years we analyzed the dynamics of the genetic structure of three coral reef fishes of the Capricorn bunker reef group (Great Barrier Reef): the cardinalfish *Ostorhinchus doederleini*, the damselfishes *Pomacentrus coelestis* and *Acanthochromis polyacanthus*. The latter serves as a control for genetic changes in reef populations without having a larval dispersal phase, while *O. doederleini* and *P. coelestis* larvae spent about 3 weeks in the pelagic. Based on microsatellite markers, in some years up to 60% of arriving settlers could be assigned to the adult reef population indicating larval homing. This might support the observed genetic differences between reef populations (distances: 6 to 23 km). However, in both species with a larval pelagic phase, dramatic changes were observed in the annual dynamics of the genetic structure; within a year, significant differences between reef populations could appear and disappear. Surprisingly, in *A. polyacanthus* without a larval dispersal phase, reef populations also showed significant changes in the genetic structure (up to 19%) between 2005 and 2011. Our results indicate that larval dispersal is not the only factor determining the dynamics of reef populations. We assume that only a part of the adult population can successfully reproduce in a given year and selection is a major driver for the population structure.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1030, Hall C

Bio-physical modeling of *Siganus spinus* recruitment around Guam

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The scribbled rabbitfish *Siganus spinus* is a medium-sized herbivore (<24cm), commonly found on the reef flats and shallow lagoons throughout Micronesia. Recruitment of this species to Guam is a 'boom or bust' phenomenon with good recruitment events often resulting in extraordinary numbers of newly settled fish moving onto the reef flats around the last-quarter moons of April-June and Sept.-Nov. These exceptional recruitment events are eagerly anticipated by the local Chamorro people with harvesting of newly settled rabbitfish having been a traditional activity for hundreds of years. There is however, very little known about the population dynamics of *S. spinus*, a parlous situation for such a heavily fished species. Utilizing a number of approaches, we built a comprehensive picture of the bio-physical processes driving the population dynamics of this species to provide a robust scientific framework for future management of *S. spinus*. Data from current meters was combined with data on the biology and ecology of this species to build a bio-physical model for investigating the range of outcomes which are possible under various management scenarios and within the context of changing climate. The efficacy of our model was determined through correlation with a 30-year creel data set on the tonnage of annual rabbitfish recruitment harvests on Guam. Our results identify a significant self-recruitment mechanism in operation.

14A The ecological importance of larval dispersal
Thursday 12 July, 1000, Hall C

How marine reserves redefined recruitment dynamics in an island archipelago

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Measuring the degree of demographic connectivity between discreet marine populations remains a long-standing challenge that has limited our ability to untangle the ecological processes that drive population dynamics. With the increasing success of marine reserves as a management tool for coral reef fisheries, the increased reproductive potential of important fisheries species within their boundaries is likely to have an important role in shaping local population dynamics. Using genetic parentage analyses, we investigate the influence of a marine reserve network on the spatial and temporal variability of recruitment for two highly exploited coral reef fish species (coral trout - *Plectropomus maculatus* and stripey snapper - *Lutjanus carponotatus*) in an island archipelago of the Great Barrier Reef. We estimated that marine reserves, which cover approximately 28% of the reef area in the island group, were producing ~50% of all local recruitment for both species, a staggering contribution for a local population that received only ~5% immigration from distant populations over the same period.

We further investigate the community structure of these species by exploring the relatedness of individuals throughout three successive cohorts. As a major source of recruitment to the island group, we show that this marine reserve network played an important part in shaping local population dynamics.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1745, Hall C

Species-area relationships and distribution patterns of damselfishes under random colonization

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Coral reef communities are usually linked by obligate larval dispersers, which often randomly settle on their respective habitat patches. While coral reefs are often characterized by ecological zonation, random colonization may be a key determinant of the metacommunity structure across patchy habitats within a zone in a coral reef. Given that, the total area of the habitat patches is likely to shape the structure. Submerged coral reef shore zones often harbor small patchy reefs (i.e., discrete habitat patches) with local fish communities, which may provide a model of the coral reef metacommunity structure in relation to random colonization. Previously, we examined species-area relationships of damselfish assemblages on 84 discrete large and small reefs in a shore zone of Shiraho reef, Ishigaki Island, Okinawa, Japan. Species richness in large reefs was significantly lower than had been expected from random placement computer simulations. Interspecific territorial herbivores, such as *Stegastes nigricans*, coexisted only in large reefs. In the present study, we examined coral coverage, reef height and 3 dimensional habitat segregations of the territorial herbivores to determine why species richness in large reefs was smaller than expected. We discuss the relationships between local and metacommunity structures with regard to reef area, height, coral coverage and interspecific interactions of territorial herbivores under random colonization processes. If size distributions of patchy habitats (with coral coverage) shape metacommunity structures, total species richness should be predictable based on seascape structure, which is usually well reflected in aerial photographs.

14A The ecological importance of larval dispersal
P133

Local retention, self-recruitment, dispersal and variable connectivity among reefs

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The persistence and resilience of marine populations in the face of disturbances is directly affected by connectivity among populations. Thus, understanding the magnitude and pattern of connections among populations is critical for effective management and conservation of marine species. We use two independent techniques - population genetics and otolith microchemistry - to track the dispersal and identify source populations for the larvae of a common Caribbean coral reef fish (*Stegastes partitus*). We quantify the extent of connectivity, dispersal, self-recruitment and local retention within and among several populations in the Mesoamerican barrier reef system, sampled over a six-year period. We found that some larvae disperse long distances (>200 km); however, self-recruitment was a regular phenomenon. Importantly, we found that dispersal distances, self-recruitment, local-retention and the pattern of connectivity varied significantly through time. Our data highlight the unpredictable nature of connectivity, and underscore the need for more, temporally replicated, empirical measures of connectivity to inform management decisions

14A The ecological importance of larval dispersal
Tuesday 10 July, 1545, Hall C

The scale of dispersal in brooding and spawning corals

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Coral cover is declining in many regions of the world, due to declining recruitment and elevated mortality. We investigated recruitment and the scale of stock-recruitment relationships for brooding and spawning corals across the Great Barrier Reef. On 24 reefs, we measured adult abundances and fecundity, settlement of corals onto plates, and the density and composition of recruits on reef substrates. For all brooding taxa, the number of settlers and recruits was strongly and positively correlated with local (reef-scale) adult abundances. For spawners, adult abundance was unrelated to settler or recruit density. These results indicate that brooders are self-recruiting at the scale of individual reefs. If the local brood-stock is

depleted, recruitment diminishes. In contrast, the local loss of adult spawners, does not affect their recruitment so long as another source of larvae is available nearby. These new results are consistent with genetic studies of corals, and observations of recruitment failure on isolated oceanic reefs following coral bleaching. The difference in scale of stock-recruitment relationships in brooders versus spawners reveals an important mechanism that could drive down the adult abundance of brooders faster than spawners. Across the Great Barrier Reef, brooders are much less abundant than spawners on reefs that have lost the most cover over the past 25 years. In contrast, brooders and spawners are equally abundant on the few remaining high-cover reefs.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1530, Hall C

Coral recruitment after a bleaching event in the Red Sea

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Coral recruitment patterns can provide evidence of inter-reef connectivity and indicate a reef's potential for recovery. In summer 2010, high temperatures combined with low winds led to an important bleaching event on many inshore reefs off the coast of Thuwal in the Saudi Arabian Red Sea. We set up a long-term monitoring project on one of the affected reefs. In April 2011, 60 settlement plates were placed on Abu Shosha Reef, to be replaced every three months. Surveys showed a very low live scleractinian coral cover (6.84%) since the bleaching incident in summer 2010. After the first 3 months, a total of 102 living and 24 dead scleractinian recruits were counted on the bottom-facing sides of the plates. While pocilloporids were the most dominant recruits on the reef (57.8%), about 20.6% of living recruits belonged to the family Acroporidae, a family whose live cover on the reef is extremely low, which may suggest recruitment from other reefs and a possibility of replenishment. However, the overall average density of recruits was very low (average 1.7 living recruits/plate) compared to similar studies elsewhere in the world, and 40% of plates had no hermatypic recruits whatsoever. We also carried out fish surveys to assess the general health of the reef system and particularly that of the herbivore community. We discuss the implications of these results on the reef's ability to recover and the potential consequences of future bleaching events on other reefs nearby with similar local environmental conditions.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1645, Hall C

Growth histories and life in the plankton of neon damselfish

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During the presettlement phase larval reef fishes depend on plankton to grow further, they must find a suitable settlement site. Otolith microstructure, and chemistry, can provide great insight to the early life of fish in the plankton. The purpose of this talk is four-fold: (1) describe variation in PLD and presettlement growth at different spatial scales; (2) use daily increment widths as a proxy of growth; (3) use elemental analyses and patterns of growth to elucidate occupancy of near reef waters; (4) experimentally determine the influence of temperature and food on growth. Our focus was on *Pomacentrus coelestis*, an abundant species of fish on the mosaic of reefs that is the Great Barrier Reef. *P. coelestis* spent 15 to 26 days in the plankton and this was consistent between years and reefs. Potential settlers of a variety of sizes were found near reefs and elemental signatures suggested they may spend 0-5 days near a reef before settling; they also behave differently in reef versus ocean waters. There was great variation in patterns of growth at spatial scales of over 1000 kilometres. Growth was fastest from ~5 to 15 days and slowed as fish approached settlement. Experiments demonstrated that temperature and food affected growth, but within a temperature range of 28.5 to 31°C all variation in increments widths could be explained by variation in amount of food. Otoliths can provide an accurate record of feeding conditions and fine scale resolution of variation in plankton supply.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1645, Hall C

Picking the perfect birthday: reproductive biology and connectivity in octocorals

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The Caribbean octocoral *Pseudopterogorgia elisabethae* is a surface brooder which in The Bahamas spawns on a lunar cycle in November and December. The larvae are negatively buoyant but swimming behavior slows sinking rates. Predictions of dispersal and larval retention from 2005-2008 were developed using a bio-physical model, which simulated traits of the larvae and a high resolution characterization of flow dynamics in The Bahamas. The model predicted high levels of larval retention which is concordant with the observation that recruitment rates at sites were correlated with local density. Among those larvae that do disperse the model predicted modal dispersal on the scale of <10s of kilometers. That result is generally concordant with genetic data that show limited (pairwise Fst<0.05) structure among populations separated by 3-70 km with greater differentiation among more distant populations. Both the simulations and genetic data indicate that current patterns and suitable habitat are better predictors of connectivity than distance. The model was used to compare the potential effects of reproducing at different times of the year on retention and dispersal. Spawning during the observed spawning months generated higher levels of local retention and lower large-scale connectivity than spawning spread out over the entire year. Gonochoric species must exhibit some degree of synchronicity in their spawning in order to effect successful fertilization, but the basis for the timing of those synchronous events is not apparent. Bio-physical models provide a valuable tool in exploring the consequences of that timing on successful recruitment.

14A The ecological importance of larval dispersal
Thursday 12 July, 0930, Hall C

Greatly varying realised larval dispersal in broadcast spawning corals

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Pelagic larval dispersal is the main means by which benthic reef organisms can maintain demographic connectivity and gene flow among populations and reseed distant reefs following disturbances. As such, larval dispersal is critical for benthic taxa such as reef-building corals. We evaluate connectivity for *Acropora tenuis* and *A. millepora*, two common broadcast spawning *Acropora* species on the Great Barrier Reef (GBR) using hierarchical approaches spanning large, intermediate and small spatial scales and 11 polymorphic microsatellite loci. Large-scale population genetic processes were elucidated from comprehensive sampling (spanning 12 degrees of latitude and >1,500 km) of inshore and offshore reefs throughout the GBR. We genotyped 947 colonies from 20 reefs for *A. millepora* and >1500 colonies from 32 reefs for *A. tenuis*. *Acropora millepora* shows a major divide between the southernmost reefs and all other sampled reefs, as well as strong cross-shelf genetic division. Most northern inshore and mid-shelf populations are open, exchanging recruits frequently. In contrast, inshore populations south of 21.5 latitude and offshore populations in the central and southern GBR are largely self-seeding. Results for *A. tenuis* are still being finalized. High-intensity sampling of *A. tenuis* was conducted at the Lizard and Orpheus Island groups (>1000 colonies from 10 sites in each island group) and the exact GPS location and size of each sampled colony was recorded. We use these data to investigate fine-scale genetic structure among sites and between cohorts of different size classes. The results of our study are compared with predictions from bio-oceanographic larval dispersal models.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1630, Hall C

Connectivity of *Acropora millepora* along the coast in Vietnam

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In order to design marine reserves and protect coral species in an efficient way, it is of great importance to understand the distribution patterns of species and the genetic connectivity patterns, as some sites may act as sinks and some as genetic sources. The present study took place along the 3200 km coast in Vietnam with reefs displaying remarkably high species diversity. The study ranged over 11 degrees of latitude and 2 monsoonal regimes. The aims of the ongoing study was to determine the connectivity of the spawning coral *Acropora millepora* and to determine genetic diversity and possible isolation in relation to the monsoonal regimes. The second aim was to detect different and possibly fewer genotypes in the much colder north, close to the distribution limit of the species. We used 10 polymorphic microsatellite markers to assess the genetic diversity. The consequences of the results will be discussed in detail.

14A The ecological importance of larval dispersal
P135

Predicting fish connectivity among marine protected areas under climate change scenarios

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This presentation aims to introduce a modelling approach developed to produce scenarios of climate change on genetic connectivity among Mediterranean Marine Protected Area (MPA). MPAs are used throughout the world to preserve habitats and biodiversity but are also considered as effective tools to manage fishery activities by promoting spillover through dispersion. However uncertainties remain about their optimal design to maintain regional populations. This is even more challenging within the context of climate change, likely to modify species geographic ranges and dispersal abilities. Dispersal among reserves depends on landscape (currents) and biological (survival, climate niche) features. The effect of climate change on marine organism dispersal among reserves has largely been neglected because it remains challenging to predict. We will develop predictive scenarios of climate change on genetic connectivity among Mediterranean MPAs using a simulator of genetic connectivity in complex landscape. These predictions will be derived from a GIS database containing landscape features, fish's distributions, projected climate change, and locations of marine reserves in the Mediterranean Sea. This work would carry out the first macroecological study of connectivity among MPAs linking species ranges, landscape genetic and global change with practical implications for MPA network design and fishery management, based on gap analysis and reserve-selection methods.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1250, Hall C

Radar-based tracking of pollutants and larvae in the Coral Sea

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Lagrangian dynamics are used in physical oceanography to follow a parcel of water as it moves along its flow path and changes shape. Buoyant particles can be tracked to understand and predict the movement of pollution, flotsam and biota on the sea surface. We used data from a high-frequency radar system to compute radar-based Lagrangian trajectories in the Capricorn Bunkers region of Great Barrier Reef. Validation of the radar-based trajectories is given by comparison with the paths of surface satellite-tracked drifting buoys. This paper describes case studies for the tracking of material from the Shen Neng I grounding on Douglas Shoals in 2010, and destination of water flowing from the Gladstone Harbour on ebb tides in September 2011 at the time of a fish mortality event. Further, the movement of a passive buoyant particle (larvae) can also be inferred from Lagrangian tracking, which is a valuable technique to study connectivity among reefs. Radar-based trajectories show that wind and tidal conditions greatly affect the advection of particles near surface, and the timing of larval release is crucial to determine the degree of larvae retention or advection. We have made a scenario calculation for intermittent release from a single point in the Great Barrier Reef Lagoon to illustrate the capability of the methodology for connectivity research, and discussion is commenced on how to couple this with a behavioural model to predict migration paths of larvae.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1515, Hall C

Latitudinal variation in early life history traits of coral reef fishes

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Water temperature is one of the main environmental factors controlling the physiological processes of fish larvae and ocean temperature is predicted to increase with global warming. Experimental studies have shown a strong relationship between temperature and early life history traits such as larval growth, condition and pelagic larval duration (PLD). However, the effects of temperature on coral reef fish larvae have received little attention in the natural environment. The present study examined latitudinal variations in early life history traits of five species of coral reef fish from two families (Pomacentridae and Labridae) in relation to natural latitudinal temperature variation. Recently settled fish were collected from seven locations from northern Papua New Guinea (Kavieng) to the southern Great Barrier Reef, spanning 21° of latitude. Otolith microstructure was analyzed to assess PLD, daily growth, size at age, condition (for the Labrid species) and size at settlement. Preliminary results from latitudinal comparisons for two species revealed an optimal temperature slightly above 29℃ where the highest larval growth, shortest PLDs, and largest settlement size were observed with fish collected from the northern Papua New Guinea (warmest) sites having lower larval growth and longer PLDs. This latitudinal pattern was likely to be shaped by

either: 1) Species-wide thermal optima, 2) local adaptation, or 3) location-specific environmental and demographic characteristics. The significant correlations of early life history traits with natural temperature gradients strongly emphasize the susceptibility of fish larvae to expected oceanic temperature increases.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1730, Hall C

Reconstructing larval connectivity in the Red Sea

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Despite the key role of larval connectivity in determining the population dynamics of many marine species, it remains a poorly understood process. The ideal system to investigate population connectivity would consist of a species with fully sedentary adults (thus all movement occurring in the pelagic larval stage) in a relatively isolated sea basin with a simple geographic layout such that oceanographic currents can be modeled with reasonable accuracy. The anemonefish *Amphiprion bicinctus* in the Red Sea closely resembles such a system. In this study, we collected tissue samples from more than 2000 individuals from 30 locations spanning the whole Red Sea basin, and genotyped them for 40 polymorphic microsatellite loci. We use this large-scale dataset to quantify the geographic patterns of genetic similarity across the Red Sea, and compare them to the predictions of a spatially explicit genetic framework informed by a three-dimensional model of oceanographic currents (the state-of-the-art NEMO framework, http://nemo2.sourceforge.net/). By fine-tuning different larval behaviours (e.g., extent of vertical migration, ontogenetic changes in attraction to reefs), we build a realistic scenario that describes connectivity across the whole Red Sea basin for *A. bicinctus*. Our study will provide a blueprint of how large-scale population genetic datasets, in conjunction with detailed oceanographic models, can be used to infer larval behavior and its effect on metapopulation connectivity.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1715, Hall C

Reef fish connectivity at the Brazilian coast: management and conservation

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As management and conservation policies are turning to the establishment of marine protected areas (MPAs), the degree of genetic connectivity among populations is critically important to keep those MPAs working properly. However, due to larval behavior, it is extremely difficult to predict patterns of connectivity or self-recruitment occurring at such MPA bounders. With the aim of supporting future establishment of an MPA network along the Brazilian coast, we selected four fish species (*Coryphopterus glaucofraenum, Stegastes pictus, Diplodus argenteus, Haemulon aurolineatum*) representing the main spawning strategies observed in reef fishes, to assess level of connectivity at a large spatial scale. We selected seven study sites along the coast, from North to South, to fish sampling. We used two mitochondrial molecular markers with different evolutionary rates: cytochrome *b* and control region. Phylogenetic analyses were done employing methods of Neighbour Joining and Maximum Likelihood. The population analyses were done by estimating the inbreeding rate (FST) and by analysis of molecular variance (AMOVA). The demographic estimates were based on the theory of coalescence. For *Coryphopterus glaucofraenum*, sampled populations along the coast have high levels of geographical structuring for cyt *b* and moderate levels for the control region. Populations of *Stegastes pictus* showed no geographical structuring for cyt *b* and very low levels (not significative) for the control region. Our demersal spawning models (*Diplodus argenteus, Haemulon aurolineatum*) indicated no signal of geographical structuring among the sampled populations for both markers. This information and other studies will support the design an effective MPAs network in Brazil.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1700, Hall C

Empirical measurement of single-generation larval dispersal kernels with genetics

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Despite the central role that dispersal plays in the population dynamics, biogeography, and evolution of coral reef species, empirical measurements of dispersal distances have remained difficult and rare. One particularly useful way to characterize dispersal is as a kernel whose width and shape indicates the probability of larvae settling at various distances from their parents. In this project, we measured the width of dispersal kernels using isolation by distance genetics in three species of anemonefish (*Ampiprion clarkii*, *A. percula*, and *Premnas biaculeatus*) to examine how kernels vary between species and between locations (Philippines and Papua New Guinea). Species were genotyped at 13-16 microsatellites for 8-18 populations distributed across 150-250 km of coastline. A key methodological advance was the ability to estimate effective population density from cohort genetics, ecological surveys, and variance in reproductive success. We find that dispersal kernels have a standard deviation of 10-20 km, which suggests that dispersal is often substantially further than previously suspected for these species. The species with rare habitat (*P. biaculeatus*) appears to have the longest dispersal, suggesting an interaction between settlement habitat and larval behavior. Finally, we validated these kernels against direct, parentage-based methods that tracked individual larvae and measured the rates of immigration into populations. We show that both methods agree on dispersal distances if the spatial patchiness of habitats is considered. While we have validated isolation by distance methods on anemonefish, the advantage is that they can now be applied across a wide range of species.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1015, Hall C

Individual-based genetic analysis reveals underlying population dynamics of a reef fish population

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The development of highly variable markers has allowed the genetic discrimination of individuals within and among populations and generations. The advent of high throughput technologies means that many samples and hence many individuals can be screened. To date, individual based genetic identification has been mostly used in the context of parentage analysis. However, these advances mean that we can now use genetic identification from small tissue samples to track individuals though time, allowing us to monitor survival and reproductive success through the life cycle. Here, we genetically sampled the entire population of clownfish (*Amphiprion percula*) surrounding Kimbe Island (Papua New Guinea) over a 10-year period to determine individual contribution to self-recruitment, individual survival of adults over an entire generation, movement of sub-adults among host anemones. The sampling included about 1000 individuals screened for 18 microsatellites every second year. The study identified certain adults at inshore locations that made a disproportionate contribution to self-recruitment. Overall, these individual parameters and make possible to estimate the capability of a local population to maintain itself from self-recruitment, in the context of marine reserves, evaluate whether individual sanctuaries can be self-replenishing over multiple generations.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1115, Hall C

Simulating dispersal of larvae from reefs in the Coral Triangle

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We present an individual-based-model for transport of coral larvae linked to the ocean circulation/transport model ROMS (Regional Ocean Modeling System). The larval model will simulate both broadcast spawners and brooders. We incorporate four life-history characteristics: planktonic larval duration (PLD), spawning time, precompetency period, and mortality. We use only a modest number of release sites (in the Spratly Islands) because the ocean circulation data has a fairly large spatial resolution. The analysis relies on the

particle endpoint locations for each surviving individual at the end of its PLD period. These data are used to construct a gridded density kernel for dispersal from a particular release point, yielding a rough estimate of connectivity. We discuss potential implications which suggest those reefs that may be particularly vulnerable to disturbance.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1530, Hall C

Genetic population structure of *Siganus spinus* across the western Pacific

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We used microsatellite markers to assess the population genetic structure of the scribbled rabbitfish *Siganus spinus* in the western Pacific. This species is a culturally important food fish in the Mariana Archipelago and subject to high fishing pressure. Our primary hypothesis was to test whether the individuals resident in the southern Mariana Island chain were genetically distinct and hence should be managed as discrete stocks. In addition to spatial sampling of adults, newly-settled individuals were sampled on Guam over four recruitment events to assess the temporal stability of the observed spatial patterns, and evidence of self-recruitment. We found significant genetic structure across the western Pacific, with Bayesian analyses revealing three genetically distinct clusters: the southern Mariana Islands, east Micronesia, and the west Pacific; with the southern Mariana Islands being strongly differentiated from the rest of the region. Analyses of temporal samples from Guam indicated the southern Mariana cluster was stable over time, with no genetic differentiation between adults versus recruits, or between samples collected across four separate recruitment events spanning 11 months. Subsequent assignment tests indicated four recruits had self-recruited from within the Southern Mariana Islands population. Our results confirm the relative isolation of the southern Mariana Islands population and highlight how local processes can act to isolate populations that, by virtue of their broad-scale distribution, have been subject to traditionally high gene flows. Our results add to a growing consensus that self-recruitment is a highly significant influence on the population dynamics of tropical reef fish.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1130, Hall C

Larval connectivity and population replenishment in a coastal coral reef metapopulation

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Designing effective conservation strategies such as marine reserves depends to some extent on our comprehension of how marine populations are interconnected. For coral reef fishes, while there are some estimates of self-recruitment, the exchange between adjacent sub-populations has rarely been quantified. We studied a metapopulation consisting of discrete adjacent subpopulations of the anemonefish *Amphiprion polymnus* in Bootless Bay (Papua New Guinea) over three consecutive years. By combining population surveys and genetic parentage analyses, larval retention within and exchange among adjacent discrete subpopulations were measured. Our results suggest that in this coastal system self-recruitment proportions are heterogeneous among individual reefs but fairly constant through time. In general, self-recruitment rates were low (<30%) and connectivity seems to be dominant. By using individual genotypes as natural tags and parentage analysis to follow individuals and their offspring through time in the field, we showed that female size is positively associated to the number of successful offspring recruiting within the local metapopulation and that habitat degradation can have negative consequences on egg production. Finally, by applying empirical estimates of survival, fecundity and larval connectivity in a simple matrix population model, we showed that these individual subpopulations and the local metapopulation rely on external larval supply for persistence. These patterns reinforce the importance of the structure and quality of the parental environment in population replenishment and the notion of open population at the scale of tens of kilometres in reef systems where spacing between suitable habitat patches is small.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1400, Hall C

Successful invasion of *Turbastraea micranthus* into the western Atlantic

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The Gulf of Mexico experienced an invasion by the ahermatypic Indo-Pacific coral *Tubastraea coccinea*, having colonized from the Florida Keys to Brazil, reaching hundreds of thousands of colonies per site. A congener - *Tubastraea micranthus* - recently invaded the Gulf of Mexico. One oil platform out of 81 surveyed possessed this coral, occurring SW of the Mississippi River. Here, we surveyed 14 platforms in that area via ROV for both invasives, to depths of 134 m, and found it on 9. *T. micranthus* occurred in densities of up to 15 colonies/m^2 per platform; *T. coccinea* mean densities peaked at >300/m^2. Both species' densities peaked at 28.4° lat., -90° long. Percent-cover data indicated that platform GI-93C was probably the site of original colonization for *T. micranthus*. *T. coccinea* cover was 25%-45%, indicating that population equilibrium had been reached in the region. Percent cover and density were highly correlated (r=0.928) for *T. micranthus* and less so for *T. coccinea* (0.487). Most *T. micranthus* colonies were small, and colony size did not correlate strongly with density, indicating that environmental conditions supporting growth varied between sites. Depth distributions varied between sites for both species, suggesting that Mississippi River discharge was influencing this population attribute. Due to its geographic expansion rates, it is possible that *T. micranthus* could spread throughout the Gulf of Mexico and other tropical western Atlantic sites, like *T. coccinea*, becoming a major invasive species. We suggest that government act swiftly to eradicate this species before such is no longer possible.

14A The ecological importance of larval dispersal
Thursday 12 July, 0945, Hall C

Larval recruitment mechanism in 'simultaneous mass spawning' corals

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Acropora corals spawn simultaneously on full-moon nights. Although it is known that most spawned larvae settle simultaneously in a short period immediately after spawning, the processes from fertilization to settlement remain largely unknown. Clarification of these processes is essential to understand the establishment and maintenance of coral communities and to develop effective conservation programs. In this study, we clarified the settlement pattern of *Acropora* corals at different depths and in different habitats by examining data on the genetic composition (the mitochondrial control region and the nuclear ribosomal region) of settlers within a small reef off Ishigaki Island (the southern part of the Ryukyu Archipelago) from 2006 to 2011. Further, larval dynamics during drifting and swimming was estimated on the basis of the distribution and genetic composition of swimming larvae. We found that the genetic compositions of the settlers differed between regions inside and outside the reef, and even in this small-scale investigation, we observed species-specific depth zones for *Acropora* settlers and swimming larvae. Finally, the genetic compositions of settled corals were compared among different regions to determine whether the data are useful for identifying larval sources. The preliminary results showed that the genetic compositions of settlers differed between local populations 300 km apart from each other within the Ryukyu Archipelago. This suggested that the data could be used as an index of ecological connectivity (i.e., larval migration in a single generation) for *Acropora* corals.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1545, Hall C

Studying physical connectivity of reefs using a numerical ocean model

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This study uses a finite-element, unstructured grid numerical ocean model to simulate the transport of coral larvae in the Great Barrier Reef (GBR), with the aim of studying the physical connectivity between different reefs in the GBR. The SLIM model (www.climate.be/SLIM) is used to study the hydrodynamics of the entire GBR to a resolution of 200 m near reefs and islands, thus enabling us to specify the correct open boundary forcings by the Coral Sea in terms of the South Equatorial Current and the tides. The SLIM model demonstrates not just the classical cascade from large-scale to small-scales, but also a feedback from the small-scale to the large-scale. A particle-tracking module is then used to track and record the positions of coral larvae released into the simulated domain

during the spawning season, over a period of a month. Connectivity matrices for the GBR are generated from the positions of the larvae at the start and at the end of the simulations. We group the reefs into 'communities' (clusters of highly inter-connected reefs) using tools developed from Graph Theory, to identify the areas of the GBR in which reefs are most highly inter-connected. The model predicts the distribution of clusters of highly self-seeded reef as a result of the sticky water effect, and inter-connected reefs occasionally several hundreds of kilometres apart.

14A The ecological importance of larval dispersal
Tuesday 10 July, 1715, Hall C

Recruitment patterns and ecologically relevant dispersal distances of brooding corals

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Understanding ecological connectivity of populations of coral species among and within coral reefs is essential for developing evidence-based management decisions. Ecologically significant exchange of larvae among populations maintains genetic diversity, which in turn ensures reef resilience and the ability of populations to respond to changing environmental conditions. It also increases the ability of reef ecosystems to recover from major perturbations by the import of recruits from unimpacted areas. Here we present the results of a study on the assessment of ecological connectivity of the model brooding coral species *Pocillopora damicornis* and *Seriatopora hystrix* on the Great Barrier Reef (GBR). Over 3000 branch samples were collected from adult colonies from 16 different reefs ranging from Wallace Islet reef (11.5°S) to Heron Island (23.5°S), and coral recruits were sampled every two months at 8 sites around Lizard (14.7°S) and the Palm Islands (18.6°S) from settlement tiles throughout two years, yielding a total of 1150 pocilloporid recruits. All samples were genetically characterised by 10 microsatellite loci, and recruits were assigned to their putative source populations by genetic assignment tests. Recruitment patterns show high spatial and temporal variability, ranging between 0 and 97 recruits per site per sampling time, but is continuous throughout the year at all sites. Coral recruits are largely retained locally, which suggests low potential for reef recovery from immigration after severe perturbations.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1730, Hall C

Decomposing larval connectivity: quantifying the consequences of larval life histories

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The larval dispersal process is critical for metapopulation persistence, range expansion, and a species' ability to cope with climate change. Unfortunately, decomposing this complex process and identifying the important biological drivers and the resultant spatial patterns remains a great challenge. Furthermore, the interaction between the seascape and these biological parameters is unclear. We explore these interactions and resultant geographic patterns using a spatially-explicit biophysical model of larval dispersal. We quantify the complex interaction between the dynamic seascape and species' larval characteristics to (1) highlight the influence of key biological and physical parameters on successful larval settlement and dispersal distances and (2) map the spatiotemporal patterns emerging from these interactions from local to regional scales. We describe the modelling approach that effectively quantifies potential larval supply across species, from demographically relevant to evolutionarily significant scales. The species-specific biological parameters include larval supply (adult density, fecundity, larval release), dispersal (pelagic larval duration, pre-competency period, behaviour, mortality), settlement (habitat availability, suitability), and post-settlement survival. These dispersal estimates are transformed into population networks where we highlight cross-species similarities, identify emergent system-wide properties, and quantify each population's contribution to system dynamics. Finally, we highlight multi-species dispersal corridors, semi-permeable barriers, critical stepping-stones, and the emergent spatial structure of marine larval dispersal.

14A The ecological importance of larval dispersal
Wednesday 11 July, 0930, Hall C

Predicting the fate of coral larvae with an agent-based model

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The Great Barrier Reef is recognised as one of the great natural wonders of the world. A significant amount of effort has been directed at

the development of research, management and policy programs aimed at ensuring a wise custodianship of this asset. Recent advances in numerical modelling provide new opportunities to assess and analyse the physical and ecological processes occurring in areas such as reef ecosystems. Agent-based modelling provides a tool for solving equations relating to ecological processes and behaviours of moving, planktonic organisms and relies on inputs readily available from a hydrodynamic model such as water levels, current velocities, temperature, nutrient concentrations etc. This paper focuses on the development of a standard model template to describe the dispersion and connectivity of coral larvae using a section of the Great Barrier Reef near Townsville as a case study. It examines the strengths of the detailed modelling approach and highlights the applicability of the results to improve management outcomes.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1230, Hall C

Life-history traits of endemic reef fishes of the Gambier Islands

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Endemism may be explained by several hypotheses including species life-history traits which limit geographic expansion. This hypothesis is tested on coral reef fishes, by comparing life-history traits during the pelagic larval stage of 4 species endemic of the Southeast Pacific and 4 non-endemic congeners collected in the Gambier Islands in October 2010. For the 4 couples, optical analyses of otoliths show that non-endemic species have shorter pelagic larval durations (PLD), faster growth rates and similar size at settlement than endemics. LA-ICPMS analyses of 6 elements (Li, B, Mg, Mn, Sr, Ba) along otolith transects indicate that each species has a different multi-elements signature and so a different larval life-history. Even if these chemical signatures allow the significant discrimination of endemics and non-endemics in each couple, no consistent pattern can be observed for all endemic or non endemic species. However, some Bore, an element used as a fingerprint of urban pollution, can be detected in otoliths of 3 out of 4 non endemics species, and important concentrations of all elements are detected in one non endemic species. This suggests that endemics may have a more oceanic larval stage than non-endemics. This is paradoxical because endemic species are expected to have a more limited potential dispersal (shorter PLD and coastal larvae) than non-endemics. A hypothesis which links oceanic oligotrophy, growth rate, PLD, habitat fragmentation and competitive relationship, is proposed to explain this paradox of life-history traits in endemic species.

14A The ecological importance of larval dispersal
Thursday 12 July, 1015, Hall C

Summary: the behavioral, population, and evolutionary consequences of larval history

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For coral reef organisms, recent studies have highlighted that settlers come from both short and long distances. The supply of larvae from a mixture of sources may be a major factor promoting the resilience of reef populations. Until recently we have known very little about the effect of larval origins on the relative fitness of individuals in a focal population. Here we summarize how this symposium has highlighted the development of techniques that enable us to distinguish among larvae of different origins and histories. This in turn has allowed us to explore the relationships among pre-settlement processes (population source, maternal effects), settlement processes (sensory mechanisms, habitat selection, conspecific interactions), and post-settlement success (survival, reproduction) to evaluate the demographic and fitness consequences of larval history.

14A The ecological importance of larval dispersal
Thursday 12 July, 1030, Hall C

Connectivity in symbiosis: integrating coral host and *Symbiodinium* spp. genetic structure

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While most coral species have broad geographic distribution ranges and larvae with significant dispersal potential, coral recruitment is mostly localized. Here, we assess genetic population structure in the brooding coral, *Seriatopora hystrix*, at local and regional scales

(100m - 100km) in order to infer the shorter range of larval dispersal occurring locally, and how that drives broad-scale connectivity of this species along the Great Barrier Reef. Moreover, we integrate genotypic data from both host and vertically-transmitted algal symbiont (*Symbiodinium* sp.) populations to facilitate a comprehensive understanding of the dispersal ecology of this symbiotic partnership. We sampled coral colonies from two sites at each of five reefs in the Palm Islands and four reefs at Lizard Island, Australia (n=850). Each island region was further separated into two habitats: sheltered-shallow (<6 m) and exposed-deeper (7-15 m) margins of islands. All samples were genotyped at ten host microsatellite markers. Samples from half of the sites were also genotyped for ITS2 *Symbiodinium* type and eight microsatellite loci to explore *Symbiodinium* population structure and diversity. Our results indicate that the coral host populations are highly structured according to habitat, as connectivity between patches of the same habitat (i.e. sheltered or exposed) even between regions was higher than that between habitats (i.e. sheltered vs. exposed) within regions. Moreover, different ITS2 *Symbiodinium* types in sheltered and exposed host populations support strong genetic and ecological separation. In comparison to studies limited to coral or algae alone, concurrent information from both partners allows a more holistic understanding of coral connectivity.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1145, Hall C

***Seriatopora hystrix*: genetic diversity and connectivity in Africa and Vietnam**

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The present study compares two studies in the brooding species *Seriatopora hystrix* (by using 5 polymorphic microsatellite loci and the mitochondrial dloop as markers) along the East Coast of Africa and along the coast in Vietnam. The results showed that in East Africa the connectivity between Northern Kenya and Southern Tanzania was high and south of Tanzania the genetic divergence was strong. The patterns can mainly be explained by current regimes. In Vietnam the preliminary results showed at least three genetically isolated regions and a higher within site diversity in high diversity areas. The results show the importance of designing marine reserves in relation to regional current, environmental and geographic differences.

14A The ecological importance of larval dispersal
P136

Modelling global dispersal and genetic connectivity of broadcast spawning corals

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Of the various factors controlling the distribution and ecology of coral reefs, dispersal of larvae by ocean currents may have particular significance to the future of reef ecosystems. Species range shifts, resilience to degradation via population replenishment and also adaptive potential via the flow of genetic material are all mediated by the dispersal and recruitment of coral juveniles over various spatial and temporal scales. Over longer time periods, global genetic structure and species boundaries are influenced by rare long-distance dispersal events. We aim to explore population connectivity on scales appropriate to global environmental change. Whilst previous models of global dispersal relating to coral biogeography have been idealised, we exploit recent advances in larval transport modelling, generally focusing on ecologically-relevant dispersal to regional scales, to develop a spatially explicit, global biophysical dispersal model for a generic broadcast spawning coral 'species'. Using the Connectivity Modelling System, a stochastic 'particle tracking' application coupled in this case to 1/12° resolution ocean current output from the global HYCOM model, and incorporating coral early life history traits and settlement habitat, we simulate the dispersal and potential connectivity of coral planulae over an 8 year spawning period (2003-2011). We explore whether this model is able to reproduce 'real world' patterns of connectivity as revealed by genetic analyses. We also discuss the potential applications of such a model in identifying vulnerable isolated locations, as well as important source and stepping stone reefs for the maintenance of genetic diversity in corals over scales relevant to future rapid climate change.

14A The ecological importance of larval dispersal
Wednesday 11 July, 1430, Hall C

14B Larval & settlement behaviour of coral reef organisms

Recruitment failure of scleractinian corals in Hong Kong

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Coral recruitment is one of the key processes involved in maintaining coral communities and facilitating reef recovery following disturbance. In this study, recruitment patterns of corals were monitored for 2 years in Hong Kong. Terracotta tiles were used as settlement substrata in two core coral areas in Tung Ping Chau Marine Park, A Ye Wan and A Ma Wan, where coral diversity is one of the richest in Hong Kong. The settlement and post-settlement survival of coral recruits were monitored at multiple spatial (site, depth) and temporal (season) scales using fluorescence census technique and microscopic examination starting in May 2009. The results revealed extremely low natural recruitment success of corals, with a total of 10 recruits recorded on 528 tiles throughout the study period. Recruits of *Platygyra acuta* pre-seeded on tiles that were subsequently grown *in situ* showed that these coral recruits experienced very high mortality following settlement, with average mortality of 78.36% within half a month and <1% survived through the first four months of deployment *in situ*. The data obtained suggest that very low recruitment of corals in the monitored sites may be due to the lack of arrival of competent coral larvae, low larval settlement; or low post-settlement survival of new recruits due to high sedimentation, intense competition for space with other fouling organisms and predation effects. However, a longer term monitoring of recruitment rate in a wider spatial scale is needed to provide a better picture of the coral recruitment status in Hong Kong.

14B Larval & settlement behaviour of coral reef organisms
P137

Juvenile reef fish assemblages of Ningaloo Reef, Western Australia

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The abundance, species richness and assemblage structure of juvenile fishes was quantified in the summers of 2009-2011 along Australia's largest fringing reef, Ningaloo in Western Australia. In total, 36,791 juvenile fishes from 120 species were encountered along 691 transects, providing an average of 53 individuals 30m^2. Recruitment rates were far from uniform in time or space. Mean abundance in 2010 was 75% lower than in 2009 or 2011. Particularly, this drop in recruitment strength co-incided with an overall increase in mean species diversity and distinct assemblage composition. Spatially, sampling across a number of scales including between locations, reef zones (back reef versus lagoon) and management zones (sanctuary versus recreational) was also highly variable. Locations varied in mean recruitment strength (23 to 111 recruits per transect) with recruitment and species richness means generally highest in the southern section of the Park. Although coral-dominated back reefs generally held higher abundances than macroalgal-dominated lagoons, species richness was similar and both exhibited distinctive assemblages. In fact, many species recruited exclusively to either back reef (16 spp.) or lagoonal habitats (19 spp.). Among these, a number of commercially and/or functionally important groups including the Emperors, Goat and Rabbitfishes recruited solely to lagoon sites revealing the value of these seasonal macroalgal habitats as critical juvenile nurseries. These results clearly demonstrate the importance of censusing all biomes within coral reef ecosystems to ensure species coverage and provide an excellent example of ecological co-evolution and co-dependency on a coral reef.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 1115, Hall C

Settlement site selection: a result of imprinting or innate preferences

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Recent studies have shown that rates of settlement by coral reef fishes to natal reefs is much higher than would be expected from random dispersal. It is possible that larval fishes imprint on the olfactory cues of their natal habitat and utilize olfactory cues to seek out their natal reefs. The capacity for coral reef fishes to chemically imprint on habitat cues has been demonstrated in laboratory settings, but the true role which imprinting plays in settlement site selection has never been demonstrated in the field. Here we show that

although the orange anemonefish, *Amphiprion percula*, is capable of imprinting on a variety of olfactory cues, field results indicate imprinted preferences are not used in anemone selection.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 0945, Hall C

Role of UVR in the lifecycle of the jellyfish *Cassiopea*

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Ultraviolet radiation (UVR)-absorbing compounds known as mycosporine-like amino acids (MAAs) are common in corals and other reef-dwelling organisms containing the symbiotic algae *Symbiodinium* spp. Adults of the jellyfish *Cassiopea xamachana* have both symbionts and MAAs in their tissues, and exposure to UVR in natural sunlight in the Florida Keys had no noticeable negative effects. However, when aposymbiotic fertilized eggs were removed from the medusa, they were found to be deficient in MAAs. As a result about 67% of the eggs exposed to natural sunlight hatched when protected with UVR plexiglass filters that block UVR, compared to less than 24% when UVR was present. *C. xamachana* eggs hatch into planulae larvae lacking a mouth and symbiotic algae, but they do possess some measurable protection from UVR in the form of MAAs. Still, planulae exposed to sunlight (+UVR) settled slower and fewer metamorphosed into polyps (=syphistomae) after 3 days, than when maintained under UVR filters. All scyphistomae took up symbiotic algae in less than one day, and concomitantly showed protective compounds in their tissues that presumably prevented UVR damage. These observations may explain why *C. xamachana* planulae settle and metamorphose in shady locations on the undersides of leaves or on vertical surfaces.

14B Larval & settlement behaviour of coral reef organisms
P138

Behavior of *Porites astreoides* larvae exposed to waterborne chemicals

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Coral planulae are induced to swim downward and begin benthic probing when exposed to waterborne chemicals emanating from the coralline algae-rubble matrix found on reefs, but the ability of larvae to cue in on these chemicals can be impeded by the presence of other water soluble substances. The goal of this study was to isolate which components of the reef biota may be releasing chemicals that nullify the effect of those coming from this matrix. Larvae of the brooding coral, *Porites astreoides*, were collected from Admiral and Pickles Reefs off Key Largo, Florida, USA in May 2009 and 2010. The effects of waterborne chemicals on swimming behavior were tested in 500 ml graduated cylinders. Treatments consisted of artificial seawater incubated with individual and multiple combinations of the following: *P. astreoides* adults, *Montastraea faveolata* adults, macroalgae, coral rubble with crustose corallines, or nothing (control). Approximately 10 larvae were added to each cylinder and the vertical positions of the larvae were determined every 15 minutes for 1 hour. In both years, treatments including conspecific and heterospecific corals were least effective at stimulating larvae to swim downward. In contrast, larval responses to waters incubated with macroalgae were variable, showing inhibition of benthic probing in 2009, but induction in 2010. Larvae were also less discriminating in 2010, a year in which severe seawater temperature declines caused significant coral mortality on inshore reefs. These results suggest that initial reef attractiveness to planulae, while varying both spatially and temporally, may be independent of coral cover.

14B Larval & settlement behaviour of coral reef organisms
P139

Chemical signaling of coral larval settlement and metamorphosis

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Larval settlement of benthic marine invertebrates is considered to rely on habitat-specific cues. While microbial biofilms have received attention as specific signals for a wide and phylogenetically diverse array of marine invertebrates, the presumed chemical settlement signals produced by the bacteria have to date not been characterized. In a collaborative project between the Australian Institute of Marine Science (Townsville, QLD) and the Centre for Marine BioInnovation (Sydney, NSW) we have isolated and fully characterized the first chemical signal from

bacteria that induced larval metamorphosis of acroporid coral larvae (*Acropora millepora*). The metamorphic cue was identified as tetrabromopyrrole (TBP) in four bacterial Pseudoalteromonads among a culture library of 225 isolates obtained from the crustose coralline algae *Neogoniolithon fosliei* and *Hydrolithon onkodes*. Coral planulae transformed into fully developed polyps within less than 2 h, but only a small proportion attached to the substratum. Larval bioassays with ethanolic extracts of the bacterial isolates, as well as synthetic TBP resulted in consistent responses of coral planulae to various doses of TBP. The lowest bacterial density of one of the *Pseudoalteromonas* strains which induced metamorphosis was 7,000 cells mm^2 in laboratory assays, which is on the order of 0.1-1% of the total numbers of bacteria typically found on such surfaces. In addition to the bacterially produced metamorphic cue TBP, crustose coralline algae harbor cues that result in both metamorphosis and attachment of coral larvae. We will report work-in-progress describing latest results of the isolation and identification of these signaling molecules of algal origin.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 0930, Hall C

Larval settlement onto reefs in turbulent wave-driven flow

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How do larvae carried in turbulent wave-driven flow settle onto coral reefs? We addressed this question using larvae of the tropical sea slug, *Phestilla sibogae*, which must land on reefs where their prey, the coral *Porites compressa*, are abundant. Field and wave-flume studies of how water and dissolved chemical cues released by *Porites* move above and within Hawaiian coral reefs subjected to turbulent wave-driven water flow revealed that cues leaching from corals are dispersed as fine filaments swirling in the waves above a reef. Therefore, microscopic larvae swimming in turbulent flow encounter odors as rapid on-off pulses. We assessed how the swimming behavior of larvae of *P. sibogae* is affected by realistic patterns of encounters with chemical cues from *Porites*, and how larval trajectories are affected by the rapidly-changing water flow over a reef. By combining these data about larval behavior with fine-scale data about spatially and temporally varying patterns of water velocities and cue concentrations above a reef, we calculated that rates of transport of larvae to a reef are enhanced ~20% by their responses to cues released from the reef. Measurements of drag on and adhesive strength of newly-settled larvae and juveniles showed that larvae can settle only in the slow-flow refuges within a reef, while juveniles can forage on the tips of coral branches without washing away.

14B Larval & settlement behaviour of coral reef organisms
Monday 9 July, 1630, Hall C

Environmental and genetic drivers of navigational behavior in coral larvae

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Coral larvae make myriad navigational decisions long before the final settlement surface is chosen. Our recent work on Curacao has uncovered various ecological, biochemical, microbial, and genetic factors that affect pre-settlement behavior in larvae of the spawning Caribbean coral species *Montastraea faveolata* and *Montastraea annularis*. Results include: 1) larval swimming speed and incidence are altered by the pelagic microbial environment; 2) larval swimming behavior is different in antibiotic-treated versus filtered seawater; 3) larvae are capable of detecting and avoiding conspecific adult coral colonies; 4) larval swimming behavior is altered by the establishment of symbiosis; and 5) larvae reared from different parent colonies exhibit differences in their swimming rates when placed in a common environment. Together, these five studies show that the locomotory behaviors of coral larvae are predictable responses to external influences, with a non-trivial role for genetic (or epigenetic) programming. Ultimately, the navigational behaviors of coral larvae have been shaped by the constraints of physiology and evolution, with sometimes surprising results. Coral larvae are therefore nothing like passively drifting plankton; they are making complicated navigational decisions all the time.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 1030, Hall C

Role of predator experience in influencing prey behaviour and survival

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Determining how prey learn the identity of predators and match their vigilance with current threat is central to understanding the dynamics of predator-prey systems and the determinants of fitness. The present study explores how feeding history influences the relative importance of olfactory and visual sensory modes of learning and how the experience gained through these sensory modes influences behaviour and survival in the field for a juvenile coral reef damselfish. We exposed fish to a high or low-food ration and conditioned them to recognize the olfactory cues (odours) and/or visual cues from two common predators. Behaviour and survival in the field over 48 h were recorded. Feeding history strongly influenced their willingness to take risk in the natural environment. Conditioning with visual, olfactory or visual and olfactory cues from predators led to fish displaying risk-adverse behaviour compared to fish conditioned with seawater alone. Fish that were conditioned with either visual, chemical or a combination of predator cues survived 15 times better over the first 48 hours than those with no experience with benthic predators. This experiment highlights the importance of a flexible and rapid mechanism of learning the identity of predators to survival during this critical life history transition.

14B Larval & settlement behaviour of coral reef organisms
Monday 9 July, 1700, Hall C

Orientation from open water to seagrass nursery habitats by larval reef fish

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Larvae of many coral reef fishes have an oceanic life stage and are capable of long-distance swimming in order to find suitable benthic microhabitat. They are known to actively orientate and select their first benthic habitat using several senses. Larvae of some reef fish do not settle on the coral reef directly, but in temporary inshore habitats such as mangroves and seagrass beds. These larvae seem to depend strongly on olfactory cues during the last stage of their journey towards these nursery habitats. Coastal seawater contains a mixture of various chemical cues, but little is known about the specific cues that can be used for orientation. Here we conducted several *in situ* experiments in which the response of a nursery species, the Dory snapper (*Lutjanus fulviflamma*), towards different olfactory cues from lagoonal water was tested. Test fish preferred seagrass-bed water above coral-reef water above mangrove water. Although test fish showed a response to heterospecific cues in isolation, such a response disappeared when these cues were offered in combination with seagrass-bed water. A strong response was found towards olfactory cues of conspecifics, as well as chemical cues from seagrass leaves only. An equal preference was found, however, for four different species of seagrass. These results indicate that nursery fish species may locate inshore habitats on basis of various olfactory cues. This flexibility could be a strategy to increase successful orientation towards isolated inshore nursery habitats.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 1200, Hall C

Larval biology of the fluted giant clam, *Tridacna squamosa*

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Giant clams are charismatic components of corals reefs in the Indo-Pacific, but they are in widespread decline. Although cultured for both commercial and conservation purposes, little research has been conducted on their reproductive development and early life history. Here we attempt to fill these knowledge gaps by conducting a series of experiments on *T. squamosa* larvae, including testing the effects of egg-sperm ratios, temperature, and salinity, on fertilization success and larval survival. Larvae produced using a 1:50 egg-sperm ratio showed higher proportions of healthy cell divisions after 3 to 4 h. At ~29.5°C fertilization success was significantly greater than at ~22.5°C, but higher temperatures were detrimental to the development of trochophores. No significant differences in either embryo or trochophore numbers were observed for the salinities tested (27° and 30°). We also examined whether substrates containing crustose coralline algae covered coral rubble (CCACR) have an effect on larval settlement and recruitment behaviour. After 4 days, larvae showed a preference for the substrate containing the most CCACR. After 6 weeks, however, no significant differences among the CCACR treatments and controls were found. We will also present the results of ongoing studies on developmental timings and settlement competency, vertical migration and swimming patterns of veligers, and the effects

of sediment on fertilization and settlement. All this research is part of a larger endeavor to culture and reintroduce giant clams in Singapore.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 1130, Hall C

A novel method to observe juvenile coral recruitment and post-settlement mortality *in situ*

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In the past, *in situ* studies investigating juvenile coral recruitment and post-settlement mortality commonly utilized the use of visual census, photoquadrats, and recruitment tiles. Although each method is a useful ecological tool, it also has constraints and limitations. Identification of coral recruits *in situ* is limited to the observer's field of vision. Reliable estimates of recruits are typically only as small as 2 cm in diameter and manipulation of the substrate is sometimes required to garner a sample population. Photoquadrat census is a rapid assessment approach that is limited to a 2-dimensional analysis. This technique is controlled by reef rugosity and the identification of recruits can result in false positives. Recruitment tiles enable research to be conducted in both the field and laboratory settings. This technique allows for the observation of early post-settlement of coral recruits with the use of a microscope but can be subjected to bias interpretations due to the manipulation of tiles which vary by material, curing, and spatial distribution. A novel method to improve *in situ* observations of juvenile recruitment and post-settlement mortality is described by integrating these common ecological methods with fluorescence census techniques. Results demonstrate, by assimilating fluorescence census, GFP (Green Fluorescent Protein) coral taxa can be identified and observed as small as 1 mm. Although this approach is limited to fluorescent coral taxa, post-settlement processes can be examined *in situ* at an earlier life stage than previously before.

14B Larval & settlement behaviour of coral reef organisms
P140

Positive and negative effects of benthic algae on coral recruitment

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As coral reefs continue to be degraded, coral recruitment becomes increasingly important for their recovery. Successful recruitment requires larval supply, larval settlement, and post-settlement survival and growth. We tested a variety of benthic algae for their effect on coral larval settlement and post-settlement survival. Crustose coralline algal species, including *Titanoderma prototypum* or *Hydrolithon boergesenii*, facilitated larval settlement for 3 brooding and 4 spawning species of Caribbean corals. *Dictyota* spp. and some species of cyanobacteria inhibited coral recruitment of *Porites astreoides*, *Acropora palmata*, and *Diploria strigosa* by reducing settlement and killing larvae and recent recruits. These competitive interactions were often driven by the secondary metabolites found in the algae and cyanobacteria. Using cellular biomarkers we found that secondary metabolites from cyanobacteria can induce sublethal stress, which makes coral larvae of *Porites astreoides* more susceptible to global stressors such as elevated seawater temperatures. Further research on how benthic species influence coral larval settlement ecology will help us to understand the critical process of coral recruitment.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 1000, Hall C

Conspicuousness influences settlement behaviour in reef fish larvae

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Coloration of coral-reef fishes has evolved within the context of the light environment and coloration of their habitat. During coral bleaching, the diversity and abundance of reef fishes is significantly reduced, and recent work has shown that fish larvae preferentially settle in unbleached corals. Coral reef bleaching dramatically changes the visual appearance of potential settlement sites for reef fish larvae thereby also changing the conspicuousness of the fish seen against this habitat (local contrast). To test whether conspicuousness influences habitat choice, 100 pre-settlement larvae belonging to 15 species of 5 families were tested in a settlement experiment. Each fish was given a choice between a healthy-looking and a bleached-looking artificial micro-habitat (dead, painted coral of various branching species) presented either in front of a bright or dark background. Global contrast was highest for bleached corals seen against the dark background and for healthy corals seen against the bright background, thereby controlling for the possibility that global contrast in addition to local contrast influences settlement behaviour. Both micro-habitats were rebuilt before each trial to control for species

preferences. Olfactory cues were identical (painted coral). In over 80% of cases, larvae showed a significant preference for the healthy-looking coral irrespective of global contrast. Predation is more likely if conspicuousness is high and it is therefore plausible that local conspicuousness should be an important driver for settlement behaviour in reef fish.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 1215, Hall C

Global environmental change impacts auditory behaviour and survival of larvae

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Coral reefs are naturally very noisy places, with a great diversity of sounds produced by fish, invertebrates, wind and breaking waves. Many families of coral reef fishes have larvae with well developed hearing, and reef noise is used as a cue for orientation as larvae settle to reefs following a pelagic developmental phase. Since reef noise provides a direct indication of the resident community, reef noise heterogeneity can be used to identify habitat type and quality - a valuable tool for management and perhaps a crucial roadmap for larval fishes. Recent evidence demonstrates that coral reef invertebrates may also utilise auditory behaviour, including orientation at settlement in lobsters and corals, and predator avoidance in many planktonic crustaceans. However, the world is changing, and coral reef environments are amongst the most threatened. Two global environmental changes predicted for the 21st Century present a serious challenge to larvae of coral reef organisms, threatening auditory abilities and eroding natural behaviour. The first is the rise in ocean acidification, which we have found breaks down the natural daytime avoidance behaviour of larval clownfish to predator noise when reared in tomorrow's CO_2 environments. The second is anthropogenic noise, which has been increasing at an exponential rate in many marine environments over recent decades. Our recent studies have demonstrated that noise affects young fish at the physiological (stress and metabolism) and behavioural (foraging and predator avoidance) level, and through masking, can greatly reduce the scope for auditory detection and orientation towards reef habitat.

14B Larval & settlement behaviour of coral reef organisms
Monday 9 July, 1715, Hall C

Settlement responses in crab megalopae to differences in ambient underwater sound

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Recent research indicates that ambient underwater sound plays an important role in the larval settlement processes of many ecologically and economically important coastal organisms, such as fish and crabs. Our research has shown that many species of pelagic crab larvae swim toward ambient underwater sound emanating from coastal habitats. Furthermore, settlement behaviour and physiology of the larvae are also mediated by ambient underwater sound. Time to metamorphosis in reef-dwelling crab post-larvae is markedly reduced when they are exposed to ambient underwater reef sound compared to a silent (control) treatment. This response is consistent across a range of species, in both tropical and temperate marine environments. More recently we have also shown that larvae respond to differences in ambient underwater sound associated with different habitat types, as well as differences in frequency composition and intensity of experimentally replayed sounds. Consistent results from a wide range of species and locations suggest that underwater sound plays a significant role in key biological processes, such as settlement and recruitment, of coastal populations of marine organisms. It also raises the possibility that anthropogenic noise could interfere with recruitment processes by disrupting these important settlement cues and leading to premature or reduced settlement.

14B Larval & settlement behaviour of coral reef organisms
Monday 9 July, 1645, Hall C

Sensory mechanisms and swimming behavior employed by coral planulae during substratum detection

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Planulae of different coral species are induced to settle and metamorphose in the presence of crustose coralline algae or marine bacterial biofilms. A comparison was made with larvae of two species, *Pocillopora damicornis* and *Montipora capitata*. For *P. damicornis*, different bacterial species have different inductive capacities, and one particular species (*Pseudoalteromonas luteoviolacea*) was strongly inductive for settlement. As settlement cues are variable for different species of coral, the sensory mechanisms utilized by larvae may be just as variable. To determine where sensors for cues are localized in coral larvae, individual planulae were transversely sectioned into oral and aboral fragments at levels ¼, ½, and ¾ of the body length from the aboral pole, then exposed to settlement-inducing substrata.

Aboral ends of *M. capitata* settled while oral ends continued to swim as expected, given the aboral end is the point of attachment to the substratum. However, in larvae of *P. damicornis*, ¾ oral ends (i.e., lacking the aboral pole) were also able to settle, suggesting that the cells used to detect cues may be distributed along the sides of the body in the aboral half. Swimming behavior was also observed by labeling the sides of larvae with dil, a red fluorescent lipophilic membrane stain. The larvae of *P. damicornis* rotated slowly on their sides when exploring a biofilmed surface, using a different side each time. This study looks at the settlement cue that induces and the sensory region in larvae that receives, enhancing our understanding of metamorphosis in coral larvae.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 1015, Hall C

Coral larvae settlement in Guadeloupe Island, Lesser Antilles

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An experiment was designed to study the coral recruitment on the Lesser Antilles reefs. First, the importance of artificial and natural substrata for the settlement of coral planulae was tested. Several types of material were used: glass, plexiglass, unglazed ceramic tiles and *Acropora palmata* dead skeletons. Each material was shaped in order to provide tiles of 20cm by 20cm. Ceramic tiles were found to be the most attractive material for planulae settlement. Considering these results, a monthly monitoring of the planulae settlement was conducted using unglazed ceramic tiles during one year. Three different depths were tested: 5m, 10m, 20m. These tiles had one smooth side and one side with grooves. Fixation on the sides of the tiles was also examined. Planulae settled on all the sides of the tiles but showed strong preferences for the external border of the underneath side. Settlement appeared to be inversely related to depth (from 5 to 20m). Larval settlement was observed all the year round, but presented an important peak between March to June. The recruitment curve presented a peak at 5m and smoothened according to depth. A catalog of pictures of coral recruits classified per family from morphological criteria is also presented.

14B Larval & settlement behaviour of coral reef organisms
P141

Patterns of recruitment success in reefs subject to multiple disturbances

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The successful recruitment of coral juveniles is a major bottleneck to reef recovery and resilience, especially in the light of lower tolerances of larvae and juveniles to environmental stressors. Coral reef communities in Southern Singapore are subjected to frequent and multiple disturbances of anthropogenic and natural origins including cyclical oceanic processes such as ENSO and the Indian Ocean Dipole. The confluence of the latter two caused mass bleaching events in 1998 and again in 2010. Coral recruitment at three reef sites was quantified using vertically-oriented unglazed terracotta tiles deployed at six month intervals from April 2009 to March 2011. Results indicated that reefs in Singapore consistently experience markedly low rates of coral recruitment in comparison with published figures, with the exception of recruits of the species *Pocillopora damicornis*. The mass bleaching event in 2010 further exacerbated low recruitment success and resulted in a severe decline in coral recruit abundance and taxonomic diversity that lasted two subsequent spawning events. Concomitant with low recruit density were increases in the proportion of damaged or overgrown recruits on retrieved tiles. Concurrent studies showed poor correlation between abundance of coral recruits and relatively high reproductive fecundity of corals at the same reefs, suggesting that both pre- and post-settlement mortality processes contribute to local recruitment failure. These findings demonstrate that reefs under chronic disturbances may experience limited recruitment in response to further stress, which has implications for future recovery potential of damaged adult corals.

14B Larval & settlement behaviour of coral reef organisms
P142

Substrate complexity and albedo preference of reef zooplankton

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Coral reefs provide demersal zooplankton with a habitat divergent in structural complexity and colour from which to choose from. Most zooplankton are known to use light to guide orientation in the water column and many reef resident species are dependent on coral crevices or interstitial spaces to hide away from

predators. By choosing the most suitable substrate, they would benefit from increased chances for survival and reproduction but little is known about whether substrate complexities and colour contrasts are used in this context. In analysing samples caught using emergence traps and experimental structures resembling natural Acropora in the coral reefs of Biodong and Tioman islands, the results demonstrate a visual capability in a broad suite of often overlooked taxa, and provide clues in demersal zooplankton that substrate complexity and *albedo* can act as criteria. In contrast to the species that are associated closely to the bottom substrate, which showed a preference for higher complexities and attraction to low *albedo*, taxa with a pelagic or nocturnally emergent lifestyle were partially or completely non-selective. Our results suggest that demersal zooplankton may respond to structural complexity and *albedo*, emphasizing further the potential implication of globally increasing bleaching and anthropogenic destruction of corals.

14B Larval & settlement behaviour of coral reef organisms
Tuesday 10 July, 1145, Hall C

Theme 15. Biodiversity & systematics

15A Biodiversity & systematics

Composition and bathymetric distribution of octocorals (Anthozoa: Octocorallia) in the south Pacific of Mexico.

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The composition and abundance of species in the octocoral communities (Anthozoa: Octocorallia) was studied along a bathymetric profile on the coast of Oaxaca, Mexico. The composition was determined through an inspection and collection of specimens down to 70m in depth. Twenty-eight species of octocorals were found, belonging to 6 genera and four families; 6 of which are to be confirmed. The composition of octocorals varied according to the depth of the sampling sites, with 11 species distributed within a 0-25m interval, and 18 between 40-70m. Only *Leptogorgia alba* was observed at both intervals. The change in the abundance of species with respect to a depth gradient was described in 6 sites: La Fuente, El Faro, Estacahuite, Secretario, La Foca, and La Boquilla. At each site 3, 10m^2 transects were extended at 5, 10, 20, and 25m. Between 5 and 10 meters *Leptogorgia cuspida* was found at the greatest density, followed by *Leptogorgia ena* and *Leptogorgia rigida*, while from 20 to 25m, *Leptogorgia alba* was the most abundant. The genera *Pacifigorgia* and *Muricea* were recorded with lower densities. According to the octocoral abundance, they are separated in two zones a shallow one (5-10m) and a deep one (20-25m), being hydrodynamic energy the limiting factor. This study suggests that the highest richness of octcorals species in the Mexican Pacific could be located in the south and at depths of 40-70m.

15A Biodiversity & systematics
P143

Urchins as modular mobile reefs in the Galápagos archipelago

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The complex structure of biogenic habitats including coral reefs, mangrove forests, and seagrass beds, shelter diverse marine communities. However, the habitats created by these foundation species are increasingly being lost to human impacts and environmental change. Are there other species that can fulfill the role of habitat provider when more widely recognized foundation species, such as corals in the Galápagos, decline? I conducted surveys and experiments to examine whether the slate-pencil urchin (*Eucidaris galapagensis*) provides a biogenic habitat on subtidal walls in the Galápagos archipelago. The spines of a typical slate-pencil urchin have an average surface area exceeding 280cm^2, and are more than 90% encrusted with a diverse epifauna. The spines on a single urchin can host over 20 species (e.g., sponges, ascidians, bryozoans, corals, molluscs, worms, and crustaceans). Because slate-pencil urchins are consistently abundant throughout the Galápagos, the total surface area of urchin spines can rival that of the primary rock substrate. This biogenic substrate is particularly valuable in the Galápagos because substrate availability limits small-scale species richness on subtidal walls. Like other foundation species, urchins can provide a shelter from predators among their spines. Unlike previously recognized foundation species, however, the urchin habitat is modular and mobile, and has the potential to redistribute the animals piggybacking on urchin spines. Characterizing the role of slate-pencil urchins in the Galápagos will strengthen our definition of foundation species and generate an understanding of how they can maintain biodiversity in unexpected ways.

15A Biodiversity & systematics
Monday 9 July, 1700, MR5

The scleractinian fauna of Yemen: diversity and peculiar distribution patterns

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The diversity of the hitherto little known scleractinian coral fauna of Yemen was investigated through surveys extending from the Kamaran Island area, in the southern Red Sea, to Socotra, and including Aden, Balhaf, Bir Ali, Burum and Al Mukallah in the Gulf of Aden. Reef coral diversity and species distribution are principally controlled by hydrology and hydrodynamic factors. In particular, a strong seasonal upwelling linked to the SW monsoon, blowing from June to the end of August, is a major forcing function prevailing in the Gulf of Aden and Socotra. A marked East-West gradient of decreasing upwelling intensity, however, is observed along the south coast of Yemen and this imparts significant

differences in the coral fauna at different locations along a relatively short stretch of coastline. Moreover, at the local level, the fresh water input of Wadi Hajr could play an important role as an ecological barrier for coral species distribution. Overall, and as expected, our studies show that the scleractinian fauna of the Gulf of Aden is notably different from that of the southern Red Sea and is basically an impoverished West Indian Ocean fauna. However, it includes some genera and species typically restricted to the seas around Arabia and to the Indian Ocean. Finally, a new coral species was described from the area and new geographic records were reported.

15A Biodiversity & systematics
Tuesday 10 July, 1015, MR5

Endemic macrobenthic fauna on the Brazilian reef ecosystems

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The Brazilian reef ecosystems had expanded its biodiversity in recent years with the description of several new species, and is considered an important province because it has the only true reefs in the South Atlantic. This study identified the degree of endemism on the Brazilian reefs macrobenthic species. Two reef areas on the northeastern coast, mentioned by Laborel, were included in this study. First is the 600km long reef coast, located from the Rio Grande de Norte state (approximately 6°S) to the mouth of the São Francisco River, on the south of Alagoas state (approximately 10°30'S). Here, coral and sandstone reefs exist in the offshore zone and near the beach line, and exhibit a platform top which remains exposed during low tides. The second area is located on the central coast of Bahia state (approximately 12°35'S). Here, coral and sandstone reefs extend to the Abrolhos region (approximately 18°S), and exhibit fringing reefs, isolated columns, and banks offshore. This study examined the macrobenthic diversity which exists in the northeastern coast. Represented by Porifera, Demospongiae were 150 species, Cnidaria, Scleractinia were 15 species, Bryozoa were 146 species, and Echinodermata were 51 species. Among these species, a total of 72 are endemic to the Brazilian reefs, including 15 Porifera spp (10%), 6 Cnidaria, Scleractinia spp (40%), 48 Bryozoa spp (32.88%), and 3 Echinodermata spp (5.89%). The results showed the recent increase in studies of the marine biodiversity and found a large percentage of macrobenthic species to be endemic to Brazilian reefs.

15A Biodiversity & systematics
P144

Biodiversity and trophic potential across a gradient of framework degradation

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Coral reefs are biodiversity hotspots and are considered the marine analogue of tropical rainforests. Like rainforests and their well-known insect fauna, the vast majority of reef-associated metazoans live cryptically within recesses and cavities. Despite their high biodiversity and myriad trophic roles, the cryptofauna remain understudied relative to the epibenthos and nekton. Cryptofauna associated with living coral and dead reef substrates typifying successive levels of degradation were sampled on a *Pocillopora* reef off of Isla Contadora in the Pacific Gulf of Panama. Whole-reef species richness, as well as community abundances and biomass, were estimated for motile cryptic metazoans greater than 2 mm long. A total of 289 distinct taxonomic groups from 6 phyla were collected. Cryptofaunal communities associated with living corals contained higher densities of obligate symbionts, but were less speciose than those living on dead coral substrates. Multiple techniques show a consistent pattern of increasing cryptofaunal species richness as intact frameworks degrade to rubble. Therefore, while live coral is ultimately responsible for habitat construction, eroded and heterogeneous dead coral materials provide an important substrate for the majority of motile cryptofaunal species. Both intact and highly eroded frameworks contain depressed cryptofaunal biomass and substrates of intermediate erosion shelter communities with the highest trophic potential. Experimental studies suggest that these relationships are due, in part, to porosity and flow, though community-level patterns are complicated by the unique trophic requirements of their constituent taxa. These data have important and unforeseen implications into how reef communities will respond to climate change and ecosystem degradation.

15A Biodiversity & systematics
Monday 9 July, 1530, MR5

Patterns in coral community structure at Isla Lobos Reef, Southwestern Gulf of Mexico

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Isla Lobos is the northernmost reef on the southwestern margin of the Gulf of Mexico, and

like the others reefs in the area, these are frequently influenced by the action of natural (each winter cold fronts decrease seawater temperature and increase surf and turbidity) and anthropogenic (chemical pollutants, unrestricted recreational diving, ship groundings, sewage effluents etc) stressors. It's well known that some of these factors influences the coral community structure, so the aim of this work was to contribute to information about this coral reef and assess its condition. For this purpose, structural patterns on windward and leeward fore-reefs were compared at shallow (5-10m) and deep (10-15) depths. At 5 sites of the reef, we used 40 transects lines (50m each) underwater digital photography, and employed Coral Point Count with Excel extensions (CPCe). We estimated coral cover, species richness, abundance, and Shannon- Weaver diversity. So far, the results show that the most common species are *Colpophyllia natans, Montastraea cavernosa* and *Siderastrea siderea*. Leeward has more species, more coral cover, and more abundance and diversity than windward; significant differences between these 2 sites might be the reflex of several factors such as light intensity, depth, wave exposure, and disturbance regimes.

15A Biodiversity & systematics
Monday 9 July, 1715, MR5

Benthic cover in mesophotic and shallow reefs in Abrolhos, Brazil

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Abrolhos, the only true coral reef complex of the South Atlantic, harbors an important biodiversity that includes 10 endemic coral species and a poorly studied habitat, the mesophotic reefs (below 30 meters depth). We aimed to compare the benthic community cover on 2 kinds of reef in Abrolhos: shallow-water and mesophotic reefs. Video footages were taken using a ROV in Sebastião Gomes and Parcel dos Abrolhos reefs (2-20 m depth) and in the mesophotic region surrounding Itacolomis reef (20-60 m depth). Frames from the videos were analyzed using the point counting method from the CPCe program (Kohler & Gill, 2006) and organisms were identified to the lowest taxonomic level possible. The shallow-water Sebastião Gomes and Parcel dos Abrolhos reefs were dominated mainly by the octocorals *Phyllogorgia dilatata* and *Neospongodes atlantica*, covering ca. 16% of the bottom. Frondose algae were equally important with the same percentage coverage. The mesophotic reefs of the Itacolomis area were predominantly composed of coralline algae that covered 45.4% of the substrata, followed by frondose algae (ca. 5.6%; mainly *Dictyopteris* spp. and *Lobophora variegata*) and some sponges with 3.9%. The low sunlight incidence in that ecosystem is limiting to coral growth due to zooxanthellae needs and coral nourishment. Lower temperatures may also be a relevant explanation for differences between the reefs. Abrolhos supports a large diversity of habitats that makes it a unique ecosystem that demands conservation.

15A Biodiversity & systematics
P145

How many species on coral reefs?

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Coral reefs are vitally important habitats, estimated to house a third of known marine diversity and between 1 and 9 million species. However, they are under serious threat from direct anthropogenic pressures (e.g., overexploitation and pollution), and are at substantial risk from climate change. Despite the potential for massive loss of diversity that would be linked to the demise of coral reefs, we still have no good estimate of how many species of plants and animals are associated with this habitat. The World Registry of Marine Species eventually aims to contain all known marine species. However, this database houses no information about which of these are associated with coral reef habitats, and provides no information about the number that likely remain undiscovered. There currently remains little empirical data with which to estimate the true species richness value of coral reefs for most taxonomic groups. As an alternative to traditional data driven approaches, this study develops a formal expert elicitation technique within a Bayesian statistical modelling framework to utilize the latent knowledge of taxonomists to estimate 1) the number of formally named species in the marine environment, 2) the number of formally named species associated with coral reef habitats, and 3) the number of currently undescribed species associated with coral reef habitats. Results demonstrate the utility of expert elicitation for estimating parameters in ecology that would otherwise remain elusive, and highlight where some of our largest knowledge gaps lie with respect to the biodiversity of coral reefs.

15A Biodiversity & systematics
Monday 9 July, 1500, MR5

Distributional patterns of coral reef polychaetes

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During the recent CReefs expeditions, extensive collections of polychaetes were made at 3 Australian coral reefs: Ningaloo, West Australia; and Lizard and Heron Island on the Northern and Southern Great Barrier Reef, respectively. This study attempted to document reefal polychaete diversity, which is poorly known. Considering selected families of polychaetes, we discuss the various patterns of distribution exhibited by these families using both morphological and molecular techniques. While some species appear to be present at all widely separated sites, others are restricted to an individual site. In addition, molecular data suggests some species are widely occurring, whereas molecular data indicates suites of cryptic species present. This suggests that our initial estimates of polychaete diversityy are underestimates and that much higher diversity is present. Many of these species are new to science and will be described over time. We also found some species which appear to be introduced or else they have been exported from Australian sites to other areas of the world, but more material is needed to confirm this. Finally, we suggest that these selected families, which exhibit different feeding, reproductive, and habits, are potentially useful as surrogates of other reefal invertebrates (excluding corals) and can be used in monitoring the existing plans of managements for these areas.

15A Biodiversity & systematics
Monday 9 July, 1630, MR5

Taxonomic inventory of Scleractinia in French overseas territories

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The French corals reefs initiative (IFRECOR) initiated a coral reef biodiversity programme in the French overseas territories to centralize all data collected on reef biodiversity, and to allow access to the information on coral reef species distribution by everyone, particularly coral reefs managers. Through IFRECOR, The French Government vested the National Museum of Natural History (in Paris) with the responsibility to carry out biodiversity inventories in the coral reef systems of its overseas territories. The Natural patrimony department of the National Museum of Natural History manages the national natural patrimony inventory and all related data bases. The information is centralised and can be accessed. Diversity and distribution data are collected on coral reef taxonomic groups in close collaboration with taxonomic experts. Raw data are integrated, processed, and checked, and taxonomic and geographic reference lists are generated. Finally, the museum broadcasts the information on the web site 'Inventaire The taxonomic inventory of scleractinian corals from French reefs is now complete. It includes 442 species of scleractinian corals in reefs developed in the Pacific, Atlantic, and Indian Oceans. The number of species is : New-Caledonia 311; Wallis and Futuna 182; French Polynésia 165; Clipperton 17; Martinique 53; Guadeloupe 42; St-Martin 30; St-Barthélémy 48; Mayotte 212; Réunion 171; Eparses 62. Details on the various stages of the programme and on scleractinian coral diversity and distribution are provided.

15A Biodiversity & systematics
Tuesday 10 July, 1000, MR5

Molecular systematics of the tropical sea cucumbers, *Bohadschia* (Holothuriidae: Holothuroidea)

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The members of the sea cucumber genus *Bohadschia* (Holothuroidea: Echinodermata) are among the largest and most common echinoderms on tropical coral reefs. The taxonomic status of most species has experienced over a century of flux because the traditional taxonomic characters, the shape and size of microscopic dermal ossicles, are undiagnostic for *Bohadschia*. We provide a molecular phylogeny of *Bohadschia* based on two mitochondrial markers: partial large ribosomal subunit (16S, ~550 bp) and partial cytochrome oxidase subunit I (COI, ~660 bp). *Bohadschia* comprised a monophyletic group of ten evolutionary units, including three previously unrecognized forms. *Bohadschia marmorata* as defined by most workers consisted of several morphologically distinct evolutionary units. *Bohadschia bivittata, B. similis* and *B. vitiensis* comprised a single evolutionary unit that included distinct lineages from the Indian and Pacific Oceans. Also, the morphologically similar Indian and Pacific Ocean endemics, *B. atra* and *B. argus*, were sister. Ancestral state reconstructions revealed that *Bohadschia*'s nocturnally epibenthic lifestyle, burrowing behavior, and intraspecific color variation evolved early in the history of the genus. Ossicle shape and size were poor criteria for distinguishing evolutionary units.

Instead, the units were easily diagnosed by unique color patterns.

15A Biodiversity & systematics
Monday 9 July, 1645, MR5

Genetic connectivity of *Lutjanus russelli* (Lutjanidae) in the Andaman Sea and Gulf of Thailand

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Peninsular Thailand divides the South China Sea (SCS) from the Andaman Sea. Coastal fishes of Thailand are thus located in two oceans separated by a geographic barrier. The west coast of Thailand, however, is linked to the water mass of the SCS by a connection through the Straits of Malacca. Sources of larvae for the Andaman Sea can thus potentially come from both the SCS and Indian Ocean. However, within the Andaman Sea, surface currents flow from opposite directions, converging around Phuket; both water currents and geography may be barriers that separate population connectivity. In this study, examined distinctions in population structure of *Lutjanus russelli* (Bleeker) between the Gulf of Thailand and the Andaman Sea and also between northern and southern populations within the Andaman Sea. A preliminary study of 85 individuals revealed 9 microsatellite loci that showed potential as population markers. After analysis of the first 5 microsatellite loci, it is apparent that the population of *L. russelli* from the Gulf of Thailand is genetically distinct from populations in both the southern and northern Andaman Sea. From the limited sample so-far analysed, population genetic structures are not significantly different within the larger Andaman Sea region, although a single microsatellite locus suggests incipient sub-populations. This study demonstrates potential differences in population genetics that may imply the existence of unsuspected geographical barriers between the Gulf of Thailand and populations within the Andaman Sea, and has important consequences for the management of stocks of a vital food fish.

15A Biodiversity & systematics
Tuesday 10 July, 0945, MR5

Benthic communities along a broad latitudinal gradient on Brazilian reefs

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Brazilian reefs are distributed along the 8000km of coast (0°S to 27°S), however, few sites have been documented regarding reef benthic communities. Additionally, relatively few papers on benthic composition have been published over the past decades, most of them focused on mid-littoral rocky reefs. Therefore, there is a lack of comparative studies along infralittoral reefs. We conducted a meta-analysis of published and grey literature on reef benthic composition at the infralittoral. Additionally, new data derived from photoquadrats of 14 reef sites distributed along the coast are under analysis to provide detailed functional diversity patterns. There is a general trend of coral cover decreasing towards higher latitudes, except for the latitude 22°S, where maximum coral abundance and diversity were recorded. This is related to the extensive shallow continental shelf at the Abrolhos´ Bank. Conversely, macroalgae showed an inverse trend with its cover peaking in the southernmost reefs, and presents a higher diversity at 20°S. We suggest that the patterns of benthic composition might be driven by bottom-up processes in higher latitudes in contrast to lower latitudes where top-down forces are apparently more effective. This integrative approach is part of the Brazilian marine biodiversity research network (SISBIOTA-Mar) which is building up, for the first time, the state-of the-art knowledge base on benthic cover in Brazilian Reefs. The integration of information from benthic cover in parallel with fish feeding impact are bringing up important insights on Brazilian reefs´ structure, composition, and functioning.

15A Biodiversity & systematics
Monday 9 July, 1545, MR5

Determining trophic relationships using DNA barcoding of gut contents

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Identifying species involved in consumer-resource interactions is one of the main limitations in the construction of food webs. DNA barcoding of gut profiles provides a

valuable tool in characterizing trophic interactions. These new molecular tools using PCR libraries from gut contents can confirm consumer-resource pairings and test assumed linkages. The Moorea Biocode Project provides an ideal testing ground for documenting trophic linkages through the use of genetic signatures. Over the past 4 years, most macrobiotic species (>7000) on the French Polynesian tropical island have been digitized using DNA barcodes. We developed universal PCR primers to amplify a ~300 bp region of the COI gene to amplify and pyrosequence the gut content of generalist fish predators, including Hawkfishes and Squirrelfishes. We were able to identify a large fraction (up to 95%) of prey items to species level, using the Biocode reference library. While most species-level food webs can be reduced through assumed functional redundancy, we have found surprisingly little overlap in dietary composition among closely related species that would have been collapsed as equivalent trophic species in traditional food web analyses. Our results suggest functional redundancy in complex tropical ecosystems may be less than is currently assumed and that partitioning of trophic niches is more finely structured than previously supposed.

15A Biodiversity & systematics
Tuesday 10 July, 0930, MR5

Examining patterns of cryptic invertebrate diversity across the Mariana Archipelago

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Coral reefs are the most biologically diverse of all marine ecosystems. However, our current understanding and assessment of reef systems is largely limited to the well-known and accessible biota, especially fishes and corals. The majority of reef biomass and diversity is made up of small organisms living within its complex architecture. These communities, known as cryptobiota, are largely understudied because of resource limitations, shortages of trained taxonomists and subjectivity, biases, and inconsistencies in methods and of observers. Autonomous Reef Monitoring Structures (ARMS) are a systematic and standardized tool to assess and monitor understudied cryptobiota. ARMS attract colonizing organisms by mimicking the structural complexity of coral reefs and providing a habitat, in particular, for cryptic invertebrates. In 2009, 42 ARMS were deployed in shallow (12-15m) forereef habitats at 5 islands across the Mariana Archipelago. After a 2-year recruitment period, 36 ARMS were recovered in 2011. Mobile fauna measuring greater than 2mm were initially separated by morphospecies and identified to the lowest taxonomic rank possible. Diversity metrics were used to examine richness, evenness, and distinctness. Differences in community structure were examined across biogeographic, environmental, and anthropogenic gradients (remote, mostly uninhabited Northern Mariana Islands vs. inhabited southern islands of the archipelago). This study established the first standardized baselines of cryptic invertebrate diversity in the Mariana Archipelago.

15A Biodiversity & systematics
Monday 9 July, 1515, MR5

Diel variations in benthic zooplanktons over coral-reek kutch, India

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We investigated the precise coral-reef zooplankton ecology on a diurnal basis. Benthic zooplankton abundance, biomass and size composition from a coral reef in the Gulf of Kutch marine protected area, India., were investigated at four-hour intervals for a 48 hour period. Benthic zooplankton was collected vertically and divided into three size-classes; 100-200mm, 200-340mm, and >340mm. Diurnal variation of the zooplankton showed that the catches at night were always higher than those in the daytime and the nocturnal increase occurred most strongly in the large fraction (>340mm). Zooplankton abundance abruptly increased just after sunset, showed an additional abrupt increase 2.5 hour later, and declined sharply thereafter. The four-hour observation interval revealed a large diurnal variation in coral reef benthic zooplankton abundance.

15A Biodiversity & systematics
Tuesday 10 July, 1030, MR5

15B Seagrasses & seagrass ecosystems

Regional scale influence of the Suwannee River (FL, USA) on seagrasses

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The annual average discharge of the Suwannee River (FL, USA) watershed (25,000 km^2) is 280 m^3/s, with a mean monthly maximum discharge in February and March of 425 m^3/s. The river's plume impacts the second largest contiguous seagrass bed in the continental US, Florida's Big Bend seagrass beds, which cover over 2,500 km^2. Impacts vary with distance from the river mouth. Between 2001-2006, within 20 km of the river mouth, we documented complete loss of 1500 ha of seagrass and thinning of another 1700 ha.. Those losses resulted primarily from runoff from tropical storms and hurricanes in 2004 and 2005. Preliminary analyses of 1984 imagery suggests the losses documented for the period 2001-2006 are part of a longer period of seagrass decline, so we are now analyzing a decadal time series of imagery beginning in 1944 and continuing through 2011. In addition to seagrass areal losses, we have documented declines in *Syringodium filiforme* and *Thalassia testudinum* abundance. The vertical distribution of seagrass species, especially *T. testudinum*, suggests that Suwannee discharge might cause light stress at distances up to 80 km from the river mouth.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1715, MR5

Establishing tropical seagrass light requirements in a dynamic port environment

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Tropical seagrasses inhabit naturally turbid waters with dynamic light environments and variable water quality in coastal waters adjacent to the Great Barrier Reef. Large tidal fluxes amplify the magnitude of these conditions with extreme high and low light over relatively short time scales (i.e., hours). Large port developments in the region have the potential to confound the complex relationships between seagrass physiology and this dynamic light field with the onset of dredging and their associated plumes. Understanding the capacity for seagrasses to respond to changes in the quantity and quality of the light environment will allow for prediction of how seagrass species and populations will tolerate changes in light attenuation as may occur during large scale dredging. We present a strategy for determining seasonal-specific light requirements for an intertidal tropical seagrass community in a port environment. Locally relevant light requirements are established by describing the relationships among photosynthetic inputs and losses, tidal exposure, shifts in spectral light quality, seasonality, and the capacity to utilise below ground carbon reserves. The outcomes have provided guidelines for a mitigation strategy that is focussed on maintaining critical windows of light to support seagrass growth and longer term survival in these productive coastal ecosystems.

15B Seagrasses & seagrass ecosystems
Wednesday 11 July, 1015, MR5

Evaluating risk to seagrasses in the tropical Indo-Pacific region

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Seagrass meadows are a major ecosystem component of coral reef environments in northern Australia and the Indo-Pacific. Providing advice on the protection and management of seagrass at ecosystem or regional scales is difficult because of the costs and difficulties associated with collecting and analysing data at that scale. To address this, we combine geospatial data with qualitative measures of the vulnerability of seagrass habitats from multiple threats and evaluate the risk to seagrass at a local, regional, and global scale. In the Great Barrier Reef World Heritage Area (GBRWHA), the highest ranked threats were agricultural and urban runoff, followed by coastal infrastructure. There was a spatial pattern to risk with very low levels in the remote north compared with the urbanised south. Areas with the highest relative risk to seagrasses were within 3 major industrial ports. The relative impact of multiple threats was also estimated for the Indo-Pacific and compared globally using the seagrass regions of Short et al. (2007). Agreement on threats to seagrass was consistent across the regions with the same 3 threats as found in the GBRWHA in the top 4 threats for all regions except the temperate North Pacific. Threats associated with climate change received low scores across most regions and received low scores for certainty. This approach provides an estimation of the relative importance of threats. Furthermore, it enables coastal management interventions to be directed to issues and locations that will maximise returns for investment.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1500, MR5

Growth requirements of dynamic seagrass habitats: working towards thresholds

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Seagrass meadows of the Great Barrier Reef are highly dynamic habitats. For example, growth, abundance and species composition change over seasonal and inter-annual time-scales; large disturbance events such as cyclones and flooding lead to decadal-scale cycles in population dynamics; and there are ephemeral meadows in deep water (>10m). In addition, a vast area of seagrass occurs inter-tidally, where regular exposure to extreme environmental conditions compound underlying processes. It is difficult to establish basic growth requirements in these naturally dynamic systems, however there are a number of research and monitoring programs working to describe seagrass growth requirements. One of the end goals is to develope environmental and biological thresholds that can aid in regulating impacts to seagrass meadows, provide tools to interpret monitoring data, and provide input to predictive models. In the GBR, water quality is a focus of research and monitoring because it is a strong driver of seagrass population dynamics; however, climate change is emerging as an important modifier of water quality responses and thresholds. We several key questions: i) what attributes of seagrass meadows define a shift in their health and the ecosystem services that they provide, ii) how much change is a concern (against a highly variable background), and, iii) what are the environmental thresholds associated with change? We will outline the approaches to address these questions, giving examples where possible, and summarise our knowledge of growth requirements and thresholds.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1745, MR5

Responses of seagrass to mariculture-induced physico-chemical gradients in Bolinao, Philippines

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We analyzed the gradient in nutrients and chlorophyll-a in within seagrasses beds of Bolinao, northwestern Philippines over the course of 1 year.Four 50 x 50m^2 quadrats were established along a 7-km gradient. These gradients result from the extensive mariculture activities in the area, which started in the 1980's. Seagrass species composition increased markedly from 1 (*Enhalus acoroides*) at Stn 1 (closest to the fish cage area) to 7 (*E. acoroides*, *Thalassia hemprichii, Halophila ovalis, Cymodocea rotundata, C. serrulata, Halodule uninervis*, and *Syringodium isoetifolium*), at St. 4 (the Bolinao Seagrass Reserve, farthest from the cages). Seagrass species composition in Stns 2 and 3 was variously intermediate, i.e., 4 species in Stn 2 and 6 in Stn 3. A largely similar trend was exhibited by the seagrasses in terms of density (shoot count) and biodiversity of associated invertebrates and seaweeds. In contrast, this trend was reversed in terms of biomass, with Stns 1 and 2 having significantly higher values than Stns 3 and 4., The cover trend was not as clear. The results further support earlier findings on seagrass ecosystem disturbance hypotheses, generally agreeing with established principles in ecosystem dynamics. These are discussed in the context of the potential of seagrass ecosystems to act as a 'bioshield', thereby protecting the coast and its inhabitants from the adverse impacts of local and global environmental change.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1700, MR5

Responses of a seagrass bed to fertilization and simulated grazing

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The importance of resource supply and herbivory in driving competitive interactions among species has been an important but contentious ecological issue These variables exhibit different effects on species competition when manipulated in isolation, but interact when manipulated together. We tested the direct and interactive effects of nutrient addition and simulated grazing (clipping) on the community structure of a seagrass bed in South Florida. One square meter experimental plots were established in a mixed seagrass meadow from August 2007 to July 2009. The experiment was a 3 x 3 factorial experiment: 3 fertility treatments: control, medium (0.39 g N/m^2/day, 0.06 g P/m^2/day) and high (0.77 g N/m^2/day, 0.12 g P/m^2/day) x 3 clipping intensities (0, 25% and 50 % biomass removal (G)) x 3 replicates for each treatment = 45 plots). Nutrient additions and simulated grazing were done every two months. Fertilization increased competitive dominance within the primary producers while simulated grazing counteracted this effect by removal of the dominant species. Fertilization ameliorated the negative impacts of simulated grazing while simulated grazing prevented competitive exclusion in the fertilized plots. Nutrient addition and simulated grazing both exerted

strong control on plant performance and community structure. Neither bottom up nor top down influences was eliminated in treatments where both factors where present.

15B Seagrasses & seagrass ecosystems
Wednesday 11 July, 0945, MR5

Using an underwater observatory to reveal foraging behavior of herbivorous fish in tropical seagrass beds

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Seagrass leaves are generally considered to be unpalatable or difficult to digest for fish. Its importance still remains an uncertainty in transferring energy within the food web of the tropical seagrass beds. Using an underwater observatory at Dongsha Island, South China Sea, foraging behavior of herbivorous fish in the multi-species seagrass beds was first revealed. Shoots of 4 seagrass species (*Cymodocea rotundata, C. serrulata, Halodule uninervis* and *Thalassia hemprichii*) were planted *in situ* in a quadrat within the seagrass beds and a remote stationary underwater video recorded the foraging behavior of herbivore fish. In total, 33 fish species were recorded, only 3 of which (*Calotomus spinidens, Leptoscarus vaigiensis* and *Siganus spinus*) were observed to graze directly on seagrass leaves. Their grazing activities occurred only during the day time from morning to noon. They preferred grazing on the pioneer species *H. uninervis,* having the thinnest leaves and rapid growth rate ,and grazed little on *T. hemprichii,* having thick leaves. Our results demonstrate the significance of fish herbivory on tropical seagrass leaves and the selectivity may be an important factor in shaping the canopy composition in the seagrass beds.

15B Seagrasses & seagrass ecosystems
P147

Monitoring intertidal seagrasses of the GBR and responses to water quality

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Seagrass are sensitive to environmental changes and can be monitored to detect human influences to coastal ecosystems. Measurable changes in seagrass abundance, distribution, and condition provide resource managers with advance signs of deteriorating ecological conditions caused by poor water quality. For this reason, seagrasses are considered biological sentinels. The Great Barrier Reef's (GBR) intertidal seagrasses are being monitored as part of the Reef Rescue Marine Monitoring Programme (MMP). Information from the program is being used to assess the long-term effectiveness of management actions in reversing decline in water quality of the GBR Marine Park. Since 2005, intertidal seagrasses have been monitored across the 6 Natural Resource Management regions (NRMs) adjacent to the GBR World Heritage Area. Intertidal seagrasses are currently monitored sub-regionally (habitats) at 30 sites using Seagrass-Watch as the basis. Results from the monitoring report annually on seagrass status and are incorporated into a report card for the health of the GBR. Seagrass community status is assessed using measures of seagrass abundance and reproductive effort, while epiphyte abundance and seagrass leaf tissue C:N:P elemental ratios (atomic) indicate the WQ environment. Modifiers such as edge mapping, *in situ* canopy temperature and *in situ* light are also used to interpret the data. The environmental status indicates progressive degraded water quality where plants were growing in low light environments, with relatively large phosphorus pool and excessive nitrogen pool. Further refinement of the indicators will enable greater use of these metrics for water quality management of the GBR.

15B Seagrasses & seagrass ecosystems
Wednesday 11 July, 1030, MR5

Variability in nursery function of seagrass beds during fish ontogeny

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To understand how juvenile fish demands on seagrass nursery functions determine the timing of ontogenetic habitat shift from seagrass beds to coral reefs, field tethering and caging experiments were conducted for 3

different sizes of the coral reef fish Pacific yellowtail emperor (*Lethrinus atkinsoni*), during its juvenile tenure of seagrass beds at Ishigaki Island, southern Japan. Weekly visual transect surveys of the seagrass beds found a reduction in individual numbers of over 90% before movement into adult coral habitats occurred. Tethering experiments found significantly higher survival rates for small juveniles in the seagrass bed than in the coral area, and no significant difference between the habitats for medium and large juveniles. Caging experiments identified higher foraging rates in the seagrass bed than in the adjacent coral area for small and medium juveniles, which led to higher growth rates in the seagrass bed. Prey of large juveniles transitioned from small crustaceans to large decapods and gastropods, although the foraging rates between the habitats did not differ significantly, indicating that the timing of habitat shift occurred when juveniles achieved a higher foraging success on large prey items in the coral habitat than in the seagrass bed. Overall, the seagrass bed nursery functions changed with juvenile fish body size, and the greater survival and growth rates during early juvenile stages in the seagrass beds rather than on coral reefs, contributed to the enhancement of individual numbers eventually recruited to adult populations.

15B Seagrasses & seagrass ecosystems
P148

Broad-scale comparisons of species diversity patterns of seagrass community in Okinawa and the Philippines

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Developing effective methods to monitor marine biodiversity and its functions is an essential starting point of integrated, adaptive management of coastal ecosystems. We are now establishing a broad-scale, long-term monitoring system to assess species diversity and some basic functions of coastal ecosystems at several regions in Japan and the Philippines that face different types of human-induced multiple stresses. We specially target on seagrass beds within major reef systems. Here, species composition and abundance of seagrass, benthic invertebrate animals and fish are monitored according to standardized methods. As a first step, we examined broad-scale patterns in species diversity, abundance, and species composition along latitudinal gradient from Okinawa Islands to the Philippines. The patterns of variation in species diversity and similarity are different between fish and seagrass assemblages. Spatial variation in fish is more assigned to regional variation compared to seagrass which vary more locally. The result is likely related to the fact that tropical fish assemblages in Indo-West Pacific Regions have diverged greatly over evolutionary time scales compared to seagrass that entered the sea more recently. The pattern of change in species composition and abundance along environmental gradient also vary among regions and between different types of organisms, indicating environmental stressors act differently to different types of organisms. The obtained data will be utilized for further studies to elucidate causal mechanisms for the observed changes, and to predict future changes in seagrass communities in relation to ongoing global environmental changes.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1530, MR5

An eastern Pacific seagrass meadow in Golfo Dulce, Costa Rica

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Due to limited seagrass presence, seagrass studies in the eastern Pacific have been scarce. There are only 2 seagrass species reported for the Pacific coast of Costa Rica (*Ruppia maritima* and *Halophila baillonii*). The present study is the first in 15 years which examines the presence of a seagrass meadow in the Pacific coast of Costa Rica, the first seagrass report in Golfo Dulce, and of a meadow dominated by *Halophila baillonis* for the Eastern Tropical Pacific. Meadow extension was determined in October 2010, and 10 sediment cores were sampled in duplicate (one for sediment size and carbonates, the other for seagrass and invertebrate analysis). Meadow extension was 873.6 m^2, at 1-2 m depth at low tide. Mean shoot density was 5045±1023 shoots/m^2, mean biomass/core 60.3±10.1 mg (above ground=17.7±4.2 mg; bellow ground=42.7±7.0 mg). Mean rhizome length was 3.3±1.9 cm/core, number of rhizomes/core 10±4 (5±3 of them had short shoots with leaves; averaging 1±1 shoot/rhizome when present). Mean leaf length was 1.0±0.4 cm, width 0.4±0.1 cm, and leaf area/shoot 1.3±0.8

cm^2. Mean number of leaves/shoot was 3±1, and herbivory was encountered in 10.5% from a total of 305 leaves. Only colonial hydrozoans were encountered as epiphytes (3.3% of leaves). Associated fauna with a total of 97 individuals consisted mainly of polychaetes (72 ind) in 19 families (most abundant: Orbiniidae, Lumbrineridae, and Spionidae), with 46 species identified so far. The rest of the fauna was composed of bivalves (7 ind), nemertines (5 ind), and amphipods (4 ind).

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1645, MR5

Hydrodynamic impacts on seagrass in coral reef ecosystems

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Rising sea levels may cause the deterioration of existing seagrass meadows though increased shear stress associated with altered hydrodynamic conditions. Seagrasses perform important functions for coral reefs including nutrient cycling, reduction of suspended sediments, and provision of nursery grounds for reef fish. At present, intact coral reef crests attenuate wave energy and allow the establishment of semi-protected communities such as seagrass meadows. If sea levels rise at a higher rate than the ability of a reef crest to accrete, deepening water over the reef-flat will allow increased wave energy to propagate inshore to the adjacent seagrass, mangrove and soft sediment communities. We used Lizard Island, Great Barrier Reef, as a case study to examine how hydrodynamic forcing affects linked ecosystems in a coral reef lagoon. Subtidal habitats were mapped using field data and remote sensing imagery. Current velocities and wave heights were quantified and simulated using moored instruments and hydrodynamic models. Distribution and abundance of seagrass and macroalgae were quantified using depth stratified transects. In a modelling exercise, the Gourlay model of wave breaking, transformation and set-up was applied to measured bathymetric profiles of the reef flat and lagoon system to predict how variations in water depth resulting from sea level rise will affect wave energy in the seagrasses. A known relationship between seagrass presence and benthic shear stress was applied to predict how distribution of seagrasses may alter under future hydrodynamic scenarios. The distribution of seagrass meadows will change as sea levels rise with implications for adjacent coral reefs.

15B Seagrasses & seagrass ecosystems
Wednesday 11 July, 0930, MR5

Torres Strait seagrass productivity, climate change resilience and recovery capacity

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The Torres Strait has some of the most extensive seagrass meadows in northern Australia. These meadows support populations of threatened species such as dugong and turtle and commercially important fisheries species. The central Torres Strait region is particularly important and has been referred to as a 'powerhouse' for dugong in the Torres Strait due to the extensive seagrass meadows in the area and the high number of dugong they support. It is assumed that the primary production from the extensive seagrass meadows in Torres Strait underpins much of this fisheries and traditional hunting production. Detailed data on seagrass abundance, growth rates, reproductive capacity, and community structure were collected at Mabuiag Island, Torres Strait, over a 12 month period in 2011 to estimate above-ground productivity and carbon assimilated by these meadows. During the same period, manipulative experiments were conducted that aimed to examine seagrass recovery from removal related disturbance, whilst light, temperature, and other water quality parameters were recorded to help determine resilience to future climate change. The results of the study will be discussed, including implications for how their availability and productivity as a food resource for dugong and turtle changes through time and under changing climate conditions.

15B Seagrasses & seagrass ecosystems
Wednesday 11 July, 1000, MR5

Seagrasses reduce the impacts of ocean acidification on coral reefs

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Anthropogenic CO_2 emissions are rapidly increasing the dissolved inorganic carbon (DIC) content of the world's oceans making them less saturated in aragonite reducing the capacity of corals to effectively calcify. Despite these concerns, the management of future environmental change in the marine environment remains focused on improving ecosystem resilience to high-intensity short-term stressors such as elevated temperature. Appropriate and effective management responses to ocean acidification will require actions that may require extensive ecosystem intervention. Productive primary producers such as seagrasses are large consumers of DIC, and when the seagrass system as a whole community is in a state of net autotrophy this has the potential to reduce seawater DIC concentrations and consequently alter aragonite saturation to produce an environment more favorable for calcifying organisms such as corals. If such a concept has the capacity to operate at a range of spatial and temporal scales, it has major implications for the way in which marine conservation will be approached in a high CO_2 world. The proposed talk discusses this hypothesis in an Indo-pacific context and reports the evidence currently available in its support. By using currently available data sources we model the potential influence of seagrass production on seawater chemistry. In conclusion we find sufficient evidence to support research into a more detailed understanding of this concept that enables its potential use in active conservation to support the continued viability of tropical coastal ecosystems.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1545, MR5

Range scale genetic connectivity of the tropical seagrass *Thalassia testudinum*

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The seagrass *Thalassia testudinum* is widely distributed throughout tropical and subtropical western Atlantic. Capable of long distance dispersal, previous studies in the Mexican Caribbean have shown a significant relationship between geographic isolation and genetic differentiation, indicating that propagules effectively disperse over large distances (>100 km). We evaluated the population genetic structure and genetic connectivity of *T. testudinum* across its' biogeographical range, covering >4000 km. In this extensive population genetic study, we collected data from 32 populations, screening 9 microsatellite loci, generating multilocus genotypes for 996 samples. Clonality was observed in 31 populations, indicating it is a dominant meadow maintenance strategy, although high genotypic diversity in most populations suggests that sexual reproduction is an essential life history strategy. Within species genetic diversity was high, and an AMOVA yielded a global F_{st} value of 0.19; however the standardized F_{st} was 0.57, indicating significant differences among analytical approaches and ambiguous population genetic differentiation. Using a population network approach a clear metapopulation distribution over the total range was observed. Metapopulation model applies to interpreting the pattern of pairwise population differentiation; some geographically isolated populations showing genetic similarity while near populations were highly differentiated, which reflects the opportunistic nature of *Thalassia*'s dispersal strategy. A Bayesian assignment approach revealed the presence of three bioregions that correspond to the Gulf of Mexico, North-Eastern Caribbean and Central Caribbean. Populations in the centre of the species range exhibited shared region membership an indication of the absence of strict barriers and possibly a transition zone between the biogeographic regions.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1730, MR5

Diversity, resilience, and adaptability of seagrasses in the GBR

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The long coastline of the GBR contains diverse concomitant nearshore ecosystems which are exposed to a wide variety of impacts ranging from changing water quality due to land based activities to disturbances from grazing or cyclones and floods, or from changing temperature regimes. We have been evaluating the resilience of an important component of coastal ecosystems of the GBR, seagrasses, through evaluation of population dynamics and survivorship thresholds. The seagrass dominated ecosystems of the coastal GBR can be broadly classified as estuarine, coastal, or

reefal. Each community type has a typical associated suite of species, but also phenotypes that can be defined as those that are adapted to high levels of exposure related disturbance, and those that are not. Species dominating intertidal exposed locations are those that are able to adapt to the higher temperatures, possess phenotypes that are adapted to air exposure, and are able to recover rapidly from dramatic losses in cover (through seed recruitment) and may also have broader tolerances to sort-term variability in salinity. Species less able to adapt to exposure, salinity changes, or take a long time to recruit, are found in more protected locations such as reef platforms or the shallow-subtidal fringe. An integrated analysis of life history traits with environmental variables such as light limitation and nutrient excess will enable better insights into the potential for coastal seagrass ecosystems to adapt to a variety of coastal impacts associated with development and climate change.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1630, MR5

Gaps in the meadow: does gap shape affect recovery rate of seagrass?

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Gaps are an ubiquitous feature of seagrass meadows, created by a variety of both natural (grazing and burial) and anthropogenic (boat propeller and anchor damage) factors. Circular shaped gaps in seagrass beds (sometimes known as blowouts) have been attributed to burial by marine organisms such as stingrays and anchor damage, whereas longer and narrower trough-like gaps have been attributed to dugong grazing and propeller damage. In studying the recovery of gaps in seagrass meadows, scientists often create square-shaped gaps, which are not known to occur naturally. This begs the question of whether such gap recovery experiments are realistic and applicable. This study examines the effect of gap shape and size on the rate of recovery in seagrass beds and aims to validate the results from previous gap recovery experiments. Three shapes, a circle, rectangle, and square with 2 different surface area sizes, 900 cm^2 and 2700 cm^2, were chosen to examine potential differential recovery rates. Eighteen experimentally created gaps were created in a seagrass meadow composed predominantly of *Halophila ovalis*. The experimentally created gaps were monitored fortnightly to determine rate of recovery.

15B Seagrasses & seagrass ecosystems
Tuesday 10 July, 1515, MR5

15C Physiology & ecology of cyanobacteria, & sponges

Environmental drivers and effects of benthic cyanobacterial mats

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During the last two decades, dense benthic cyanobacterial mats have become more prevalent on the coral reefs of Curaçao, Southern Caribbean. Although these mats have always been part of the reef ecosystem, their proliferation has been associated with reef degradation. In this study, we determined different environmental parameters associated with the absence and presence of these mats, their spatio-temporal dynamics, and their impact on local reef ecosystem functioning. We conducted different seasonal distribution and diversity surveys along the leeward coast of Curaçao, and monitored associated abiotic parameters, including dissolved inorganic nutrients, hydrodynamics, temperature, and light. Additional experiments investigated nitrogen fixation, nutrient uptake rates, and *in situ* nutrient release using stirred sediment chambers. Local cyanobacterial mats were highly dynamic in space and time, in fixed nitrogen, and were dominated by non-heterocystous filamentous cyanobacteria. Elevated phosphate concentrations were detected in the water column above these mats, while differences between high and low abundant sites were mainly related to hydrodynamics. Benthic cyanobacterial mats could be an additional source of carbon and nitrogen into a collapsing coral reef. Newly opened space created by reef degradation, the ability to fix nitrogen, as well as fast nutrient uptake and growth rates could drive their success. Sediments could herein play a key role by providing limiting nutrients (phosphate and iron) due to anoxic conditions created underneath cyanobacterial mats (e.g. shading sediment, recycling of organic matter/nutrients) and groundwater seepage. Further investigations are ongoing.

15C Physiology & ecology of cyanobacteria, & sponges
Wednesday 11 July, 1645, Sebel Kuranda

Mangrove sponges from Bangka Island, North Sulawesi, Indonesia

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Mangroves create peculiar ecological environments, furnishing a habitat opportunity for a bulk of species. The great majority of published information on mangrove sponge communities comes from the Caribbean rather than the Indo-Pacific. Caribbean mangroves are dominated by *Rhizophora mangle*, which has stilt roots arising from the main trunk and growing downward into the substrate supporting a great diversity of epibiotic algae and invertebrates. In contrast, in most Indo-Pacific mangroves the equivalent zone is dominated by *Avicennia* and *Sonneratia* spp., which lack stilt roots and develop pneumatophores, and by *Bruguiera* spp. with knee roots. In general, species diversity of sponges in mangroves is lower than adjacent subtidal habitats (seagrass beds, coral reefs, hard-bottom, etc.) in both the Caribbean and Indo-Pacific; the numbers of sponge species can be high, although these communities are usually made up of less than ten dominant species, and generally the same dominant species are found throughout the biogeographic area. Caribbean sponges are much better known than those of the Indo-Pacific and no data are available about mangrove sponge in Indonesia. Here, we report preliminary data about sponges species diversity of 2 mangoves mangles from Bangka Island (North Sulawesi, Indonesia) These new data will enlarge our knowledge about Indonesian sponge diversity and will allow a more detailed comparison between Caribbean and Indo-Pacific mangrove inhabiting sponges.

15C Physiology & ecology of cyanobacteria, & sponges
P149

Methods to quantify biomass of the excavating sponge *Cliona orientalis* (Thiele, 1900)

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Excavating sponges play a major role in bioerosion and carbonate cycling on coral reefs; yet, methods to measure their biomass are limited. This study aims to quantify organic and inorganic components of the dried coral skeleton of *Favia* spp. infested by the Indo-Pacific excavating sponge *Cliona orientalis* (Thiele, 1900) using the loss after combustion (LAC) method and the acid decalcification (ADC) method. The sponge tissue penetrated down to approximately 10 mm inside the 12 mm thick coral substrate, and the average weight proportions of organic content, siliceous spicules, calcareous substrate, and salts were found to be 3%, 4%, 91% and 3% of dry weight with the LAC method; and 3%, 6%, 89% and 2% of dry weight, respectively with the ADC method. Respective volumetric proportions of the organics, spicules, substrate, and salts were then calculated to be 6%, 6%, 85% and 3% of volume with the LAC method; and 7%, 7%, 83% and 3% of volume with the ADC method. We estimated that more than half of the amount of spicules may be lost with the commonly used ADC method and thus caution must be exercised. The buoyant weight method was used to quantify actual substrate weight in the fresh sponge-substrate samples and was at least 97% effective, revealing that buoyant weight can potentially be used to estimate bioerosion rates of excavating sponges. This is, to our knowledge, the first study to quantify organic and inorganic contents of an excavating sponge and its calcareous substrate.

15C Physiology & ecology of cyanobacteria, & sponges
P150

The functional response of bioeroding sponges under disturbance: an ecosystem modelling approach

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Understanding mechanisms of population regulation becomes urgent when predicting the response of populations, and ultimately the trajectory of an ecosystem, after disturbance. Coral reefs experience high levels of disturbance, yet the functional response of bioeroding sponges remains understudied. Here we: (1) evaluate the relative role of regulatory mechanisms acting on populations of *Cliona tenuis*, a common bioeroding sponge in the Caribbean; (2) explore the role of sponges in alternative stable states under disturbance; and (3) analyse the contribution of sponges to bioerosion under such disturbance regimes. We use an ecosystem modelling approach, parameterized from field observations, which considers the ecological stoichiometry of interactions among major reef dwelling species. The relative regulatory role of competition, stock recruitment limitation, and size-driven mortality was compared by validating simulating outputs with an independent 10-years dataset of population structure estimates of *Cliona* (density, cover and size structure) from Glover's atoll, Belize. Algal competition explains most of the narrow-bounded fluctuations of the observed population structure (90.9% of fit of model predictions to field observations). Increases in the disturbance regime of hurricanes, bleaching mortality, and nutrient enrichment can induce a positive numerical response of clionaids. Ultimately, following model predictions, this response alters the likelihood of alternative stable states, the identity of the dominant taxa followed disturbance and the contribution of sponges to the carbonate budget of reefs. With the concerns of reef accretion and bioerosion, we highlight the complexity of interactions among taxa and the exiting gaps in the knowledge to fully understand these dynamics.

15C Physiology & ecology of cyanobacteria, & sponges
Wednesday 11 July, 1700, Sebel Kuranda

Cyanobacterial mats in tropical lagoons of Indian and Pacific Oceans

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Cyanobacteria-dominated microbial mat communities thrive widely and year round in coral reefs and tropical lagoons, with periodic massive development of benthic blooms. We studied the diversity and spatio-temporal variation of these communities in the coral reefs and shallow lagoons of Indian Ocean and French Polynesian islands by means of 16S rRNA gene survey combined with characterization of corresponding phenotypes by macro- and micromorphology and niche occupation. The mat-forming cyanobacteria were highly diversified encompassing the entire morphological spectrum of the phylum Cyanobacteria, with representatives of Oscillatoriales and Nostocales predominant. Comparison with mat-forming cyanobacterial populations reported from worldwide locations revealed the pantropical distribution of the organisms studied. A very restricted genetic diversity was found in the dominant species, *Leptolyngbya* sp., encountered in the French Polynesian Islands by using a population genetic approach based on the ITS of the rRNA operon. There was no geographical differentiation at various spatial scales in the distribution of the different genotypes, suggesting that this species is able to spread over large distances. In addition, the spatio-temporal distribution of populations examined by mean of DGGE expressed a change of tropical benthic cyanobacteria in the mats of La Reunion Island (Indian Ocean) with an increase of the richness towards the end of the hot season. Cyanobacterial species implicated in Black Band Disease infection were identified in these mats. PCR screening of genes involved in the biosynthesis of known cyanotoxins revealed the presence of the saxitoxin gene in mats of French Polynesian Islands.

15C Physiology & ecology of cyanobacteria, & sponges
Wednesday 11 July, 1715, Sebel Kuranda

Unexpected diversity on the association Sponge-Parazoanthus in southern Japan

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Sponges are sessile invertebrates well known for having a variety of associations with different organisms, consisting primarily of invertebrates such as Zoanthid genera *Parazoanthus* and *Epizoanthus* (Cnidaria, Anthozoa, Zoantharia, suborder Macrocnemina). The sponge-zoanthid association is widely distributed in tropical and subtropical waters from the intertidal to deep sea in the Atlantic and Indo-Pacific Oceans. However, since taxonomical identification of both parties is confused due to variable morphology and wide ecological ranges, the diversity and dynamics of these associations remain poorly studied. We investigated the host-zoanthid association, with focus on the genus *Parazoanthus* in southern Japan. Sampling was performed along Okinawa Island between 5 to 30 m depths at 13 different

locations, and a further 10 previously collected specimens from Japan were used. In total, 48 samples (sponge-zoanthid) were used and the total DNA was extracted from each sample. Neighbor joining, maximum likelihood, and Bayesian posterior probability phylogenetic trees were built for *Parazoanthus* spp. Sequences using the internal transcribed spacer of nuclear DNA (ITS-rDNA) and mitochondrial 16S ribosomal DNA region. Preliminary results indicate 3 to 5 species of *Parazoanthus*, much more than the 1 or 2 species commonly described as living in the region. The phylogenetic results are compared to major morphological features, and we present the first key to these common species for southern Japan and the northwestern Pacific. Sponge diversity is still undetermined since further morphological and DNA analyses are required.

15C Physiology & ecology of cyanobacteria, & sponges
P151

Picocyanobacterial diversity in the Chuuk Lagoon revealed by barcoded pyrosequencing

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To elucidate spatial changes of picocyanobacterial genetic diversity in the Chuuk Lagoon, Federated States of Micronesia (FSM), a high-throughput bar-coded pyrosequencing technique was used for 16S-23S internal transcribed spacer (ITS) sequences. The samples were collected from 2 water masses, open lagoon water and water adjacent to mangroves. From 33 samples, partial ITS sequences were amplified by PCR using each bar-coded primers, and then sequenced by pyrosequencing method (GS-FLX Titanium). A total of 57,600 sequences were obtained, and classified into 16 *Synechococcus* and 3 *Prochlorococcus* clades. For the lagoon waters, Synechococcus clade II sequences were dominant followed by clades III, VII, IX, X. For *Prochlorococcus*, clade HLII was the dominant sequence and low-light adapted clades were not found in our samples. On the other hand, mangrove water samples showed distinct spatial differences. Mangrove waters showed no *Prochlorococcus* sequences. For *Synechococcus*, the dominant sequences were clade II and CB5. Going further away from the mangroves, there were a decreasing trend in *Synechococcus* CB5 sequences but an increasing trend for *Prochlorococcus* clade HLII. Sequence composition similar to the open lagoon water only started to appear from the sampling station located about 1 km away from the mangroves. These results suggest that habitat characteristics of the tropical lagoon drive variability in picocyanobacterial diversity. Such tropical lagoon environment might provide an appropriate location for carrying out studies on ecological niche of picocyanobacterial ecotypes.

15C Physiology & ecology of cyanobacteria, & sponges
P152

Is the cyanobacterium *Roseofilum reptotaenium* a primary or opportunistic pathogen of corals?

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Black band disease (BBD) of corals is a complex polymicrobial disease dominated in terms of biomass by filamentous, gliding cyanobacteria. The BBD community has been shown, using molecular methods, to contain several cyanobacterial genera. However, one 16S rRNA sequence is ubiquitously found in BBD samples collected from tropical and sub-tropical reefs world-wide. We have isolated 2 strains of this cyanobacterium, newly classified as *Roseofilum reptotaenium*, into culture. Neither culture is axenic - one strain obtained in pure culture did not maintain viability, suggesting that associated heterotrophic bacteria are necessary for survival. Both *R. reptotaenium* strains are capable of initiating BBD in controlled laboratory conditions in aquaria that contain only healthy experimental corals and artificial seawater. Inoculations of *R. reptotaenium* quickly develop into BBD with an infection process that is sequential. *R. reptotaenium* filaments first attach to the coral surface, then develop into a small mat as a result of growth. Populations of the sulfide-oxidizing genus *Beggiatoa* appear on the lesion surface during darkness after a few days of infection - this genus requires sulfide, thus anaerobic zones in the inoculated cyanobacterial mat enrich for and support growth of sulfate-reducing (sulfidogenic) bacteria. At this point, the outer edges of the growing mat migrates across the coral surface, leaving exposed coral skeleton in the center of the lesion. Since *R. reptotaenium* cannot be isolated into pure culture the question arises - can we call this cyanobacterium a primary pathogen? Or is this a polymicrobial disease caused by a complex opportunistic infection?

15C Physiology & ecology of cyanobacteria, & sponges
P153

Changes in sponge bioerosion: from experimental evidence to monitoring guidelines

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Reefs are suffering from various impacts. To date, we have no evidence that bioeroders experience negative effects from the same factors, and for bioeroding sponges, available data suggests the opposite. Indeed, under present pressures, sponge bioerosion rates are expected to increase. Despite the importance of the issue and an urgent demand of information for reef authorities and modellers of reef health, we lack data over time, on before-after impact scenarios, and over larger scales. Previous calls to include bioeroding sponges into monitoring programs were welcomed but not implemented, which probably relates to lack of experience and to being overwhelmed by what this task may incur. We will now recommend how this task can be achieved in a simple, low-cost way not requiring expert knowledge. We suggest targeting only the most dominant species per area, which usually belongs to the *Cliona viridis* species complex and occurs in encrusting form, which is easily spotted and quantified. Depending on site, it may be valuable to include one or two other species, as we will propose. Line intercept transects should be used to quantify bioeroding sponge abundances, and we compare this method to using quadrats or collecting rubble. The intercept method was the most simple, cheap, accurate, and reliable of the 3 methods. Abundance data need to be standardised to amount of dead substrate to make comparison between studies possible. Hopefully, our results will generate more widespread efforts to obtain data on temporal and spatial variations of sponge bioerosion.

15C Physiology & ecology of cyanobacteria, & sponges
Wednesday 11 July, 1630, Sebel Kuranda

Effects of elevated temperature on the growth of two *Lyngbya* species of cyanobacteria

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Environmental conditions associated with climate change, including rising carbon dioxide levels, ocean acidification, and increasing seawater temperatures, are negatively impacting many coral reef organisms. Cyanobacteria are predicted to tolerate or favor these environmental changes relative to eukaryotic algae and other coral reef organisms; however, few studies have directly tested the effects of these changes on the growth of benthic marine cyanobacteria. Cyanobacteria play many vital roles in the ecosystem, including acting as a food source for some herbivores (although many contain secondary metabolites that limit this ability), as well as a source of nitrogen in an environment that is often times nitrogen limited. But, they can also form harmful cyanobacterial blooms under environmental conditions that favor their proliferation. This study examined the effects of increasing seawater temperature on 2 species of benthic cyanobacteria of the genus *Lyngbya*. *Lyngbya confervoides* and *Lyngbya* sp. were subjected to elevated temperatures (+4℃) in order to measure how growth was affected over a 3 week period. There was a positive correlation between elevated temperature and growth in *Lyngbya confervoides*. Adversely, there was a negative correlation between elevated temperature and growth of *Lyngbya* sp., indicating that not all species respond similarly to changes in seawater temperature. Changes in cytotoxicity of extracts of *L. confervoides* exposed to increasing seawater temperature were also examined. This study, as well as future planned studies looking into the effect of elevated carbon dioxide levels on *Lyngbya*, will facilitate our understanding of possible changes that may occur due to climate change.

15C Physiology & ecology of cyanobacteria, & sponges
P154

15D Biodiversity & coevolution of organisms associated with corals

The parasitic flatworm *Amakusaplana acroporae*:a threat to coral reefs?

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A parasitic polyclad flatworm found in 2 public aquaria in the U.S.A has been most recently described as a new species, *Amakusaplana acroporae*. It lives on a range of *Acropora* species and if left uncontrolled, its high reproduction rate results in a parasite load that can swiftly kill the host corals. At present, neither the geographic origin of this novel coral parasite nor natural predators are known. We demonstrate that *A. acroporae* is globally distributed in ornamental *Acropora* cultures. Several locations from which *A. acroporae* is reported are in close proximity to natural reefs such as Florida, Hong Kong, and Indonesia,

which implies the risk of an introduction to coral reef ecosystems in which they might, not being controlled by natural predators, cause potential harm at an unpredictable scale. The perfect camouflage of the flatworms is due to both green fluorescent protein-like pigments and zooxanthellae contained in the guts of the parasites. Fluorometric analysis of the maximum quantum efficiency of photosystem II (Fv/Fm) showed that the zooxanthellae inside the guts are photosynthetically competent. The different ratios of *Symbiodinium* clade C-subclades in host and parasites revealed by molecular phylogeny indicate a selective survival/ retention of certain zooxanthellae types. Specimen of *A. acroporae* died 5-7 days after being isolated from the coral host. This observation suggests that the photosynthesis of the zooxanthellae does not contribute significantly to the nutrition of the flatworms. Most probably, viable zooxanthellae are retained in the guts in a commensalistic relationship for camouflage purposes.

15D Biodiversity & coevolution of organisms associated with corals
Wednesday 11 July, 1130, MR5

Microbial community dynamics of coral mucopolysaccharide layer in aquaria settings

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Research on corals and their associated microbial communities is commonly conducted in both laboratory and natural settings, and corals are often transported between the two environments. It has yet to be determined how laboratory settings affect the microbial community associated with corals, in particular with the surface mucopolysaccharide layer (SML). In this study, we monitored SML microbial community changes over time, associated with *Diploria strigosa* and *D. labyrinthiformis,* during which time the colonies were collected from natural settings and transferred to laboratory aquaria. SML samples were collected for analysis immediately after removal of colonies from the environment and subsequent samples were collected after 24 hours, 1 week, 2 weeks, and 4 weeks. The experimental corals were fragmented and set in cement between the third and fourth week. Length Heterogeneity PCR (LH-PCR) of the hypervariable domains of the rRNA genes amplified the DNA extracted from the SML samples. There was a significant decrease in microbial species evenness, though species diversity did not change significantly. The relative abundance and composition of dominant microbial groups were documented. Although amplicon numbers (overall richness) recovered, there were shifts in the dominant microorganisms/amplicons, indicating that the microbial community composition had changed. These results show that coral collected from the field and brought into laboratory settings may have a substantially altered SML microbial community. Sequencing of the communities is ongoing.

15D Biodiversity & coevolution of organisms associated with corals
Wednesday 11 July, 1145, MR5

Association between *Pedum spondyloideum* (Bivalvia, Pectinidae) and live scleractinian corals

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The nestling and facultatively boring pectinid bivalve *Pedum spondyloideum* (Gmelin, 1791) is an obligate associate of living scleractinian corals that occurs in the Indo-Pacific. It attaches byssally and lives embedded in the coral skeleton. In order to enhance the understanding of the nature of associations between *Pedum* clams and their scleractinian host corals, recent field surveys have been conducted in the northern Red Sea, the eastern Indian Ocean, and in different areas of the 'Coral Triangle'. These studies have shown that *Pedum* individuals can associate with more than 50 scleractinian species and with aggressive calcareous hydrozoans of the genus *Millepora* in the northern Red Sea and the eastern Indian Ocean, but not in the 'Coral Triangle'. Most of the host species of *Pedum* clams have a wide Indo-Pacific distribution. Although some coral species are common to the different studied sites, *Pedum* individuals do not infest the same species, indicating that the associations differ regionally. Nevertheless, the most frequently colonized corals have a massive form and occur in prominent positions. Massive forms are the most porous corals and they often experience a lower rate of mortality than foliaceous and branching forms during natural disturbances, and usually have a longer life span. Moreover, *Pedum* clams favor corals with small corallites such as *Montipora* and *Porites*. Such species have a high coenosteum-to-corallite ratio, which may facilitate infestation by providing a sufficient surface area.

15D Biodiversity & coevolution of organisms associated with corals
Wednesday 11 July, 1115, MR5

Effects of coral-host bleaching on coral-reliant invertebrates

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The high biodiversity of coral reefs can be attributed to the numerous invertebrate groups, most of which receive little attention in coral reef research. Many invertebrate species, particularly decapod crustaceans, live in close association with scleractinian corals, relying upon corals for food, habitat, and/or settlement cues. Over half of all coral-associated invertebrates appear to have an obligate dependence on live corals, and this reliance is of great concern in light of severe and ongoing degradation of coral reef habitats. Certain decapod families, such as Trapeziidae and Alpheidae, are ecologically important to their coral hosts, influencing the health and persistence of individual coral colonies. They exhibit a high degree of preference for certain coral genera, such as *Pocillopora*, which are most susceptible to climate change-induced coral bleaching and mortality. This study investigated the effects of experimental thermal host-colony bleaching on 2 decapods, *Trapezia cymodoce* and *Alpheus lottini*, both of which are obligate associates of *Pocillopora*. Bleaching of *Pocillopora damicornis* was achieved over a one-month period. Physiological condition and behaviour were closely monitored before and after the onset of bleaching. Thermally-induced coral bleaching had a significant effect on juvenile growth rates, fecundity, and conspecific competition. Each of these could potentially result in a population decline of these important coral associates, with cascading effects on coral health. Given their strong dependence on and ecological importance to corals, it is crucial that future research encompasses the vast diversity and abundance of coral-associated invertebrates, recognizing their functional roles and susceptibility to climate change.

15D Biodiversity & coevolution of organisms associated with corals
Wednesday 11 July, 1200, MR5

SymbioGBR: a web-based database of *Symbiodinium* diversity and host-associations on the Great Barrier Reef

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The endosymbiotic dinoflagellates of the genus *Symbiodinium*, associated with many coral reef invertebrates, have received a lot of attention in the past decade, particularly the influence different host-symbiont associations have on the stress response of the holobiont. However, with the rapid accumulation of information on *Symbiodinium* diversity, it is becoming increasingly difficult to assess newly acquired *Symbiodinium* data in light of previous studies and compare it to established patterns of host-symbiont specificity. Therefore, we developed the SymbioGBR database, which compiles all currently available sequence and host-association data of *Symbiodinium* reported for the GBR into a single relational database that is accessible as a web-based application (http://www.SymbioGBR.org). Here, we present a case study documenting *Symbiodinium* community, diversity within the far northern section of the GBR, and compare this data with previous patterns of diversity and invertebrate host-symbiont specificity on the GBR. A total of 770 tissue samples were collected from 55 invertebrate hosts from inshore and offshore reefs. *Symbiodinium* types were characterized using DGGE of the ITS2 of the ribosomal DNA. A broad range of *Symbiodinium* subclades were found representing types belonging to clades B, C, D and G. In total 91% of the host samples contained clade C, while 7% contained clade D or a mix of clade C/D or B/C/D. This case study demonstrates the importance of continued surveying of *Symbiodinium* diversity, with the SymbioGBR database providing a rapid means to compare such data with previous studies, and to improve our understanding of host-symbiont specificity and geographic distribution patterns.

15D Biodiversity & coevolution of organisms associated with corals
Wednesday 11 July, 1215, MR5

15F Benthic foraminifera on coral reefs

Environmental risk assessement based on foraminifera of Recife de Fora

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The Recife de Fora is a coral reef located in Porto Seguro, State of Bahia, Brazil, that represents a relict coastal carbonate platform

shaped by sea level variations that occurred along the Brazilian coast during the Quaternary period. The top of this platform is exposed during low tides, and on permanently submerged portions there are coral populations subjected to high hydrodynamic flow and nutrients input. Our objective was to evaluate this environment with respect to risk analysis. To that end, it was used benthic foraminifera as bioindicators to assess the most susceptible sites. Faunal patterns were analyzed along with SHE analysis for community structure identification (SHECSI), which is defined as the mathematical statistical distribution of the relative species abundance vector, important for biodiversity queries and risk assessment. Additional mapping of areasdenoting equilibrium/stability, decline, instability/ stress were compared to the FORAM index. The western, landward, low-flow coastal current biofacies defined at Recife de Fora show instability and in some portions even decline. The eastern, seaward portion, which faces open ocean, has higher coral cover density, and its FORAM index indicates stable to good conditions.

15F Benthic foraminifera on coral reefs
Tuesday 10 July, 1145, MR3

The FORAM Index Revisited: usefulness, challenges, and limitations

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The FORAM Index (FI) was proposed as an indicator of whether water quality supports recruitment and proliferation of calcifying, photosynthesizing holobionts. The rationale was based on observations that adult coral colonies tolerate environmental conditions that no longer support recruitment as revealed by failure of coral populations to recover after die-offs. The FI utilizes assemblages of foraminiferal shells in sediment samples. Where all shells are from small, heterotrophic taxa (FI < 2), nutrient dynamics favor autotrophic and heterotrophic organisms over calcifying symbioses. Shells of larger foraminifers that host algal symbionts raise the FI; at >25% larger taxa, FI>4; at 100% larger taxa, FI=10. Smaller taxa are further distinguished as 'stress-tolerant' or 'other'. Prevalence of stress-tolerant taxa (FI<2) typically indicates high biological oxygen demand. Although proposed for western Atlantic-Caribbean reefs, the FI has been used as a coastal water quality indicator in Puerto Rico, Florida, Brazil, Pacific Islands, Australia, and Greece. However, the FI is not as useful in Indonesia, where large Calcarinidae thrive in quite eutrophic waters. Moreover, where larger foraminifers have historically been major sediment producers, relict shells can prevail where these taxa no longer live. Another problem is that identification to genus is time consuming. The following approach might make the FI more user friendly. Because symbiont-bearing *Amphistegina* are easy to identify and are reliably sensitive to nutrification, while *Ammonia* are ubiquitous stress-tolerant forms, a modified index based on proportions of *Amphistegina, Ammonia*, and all other taxa might be as useful as the currently defined FI for most applications.

15F Benthic foraminifera on coral reefs
Tuesday 10 July, 1115, MR3

Aquaculture techniques to promote sand production by large benthic foraminifers

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Sand production by large benthic foraminifers is a major mechanism to form and maintain atoll islands. Techniques that promote sand production by foraminifers could be helpful to mitigate reduced land-forming process found in degenerated coral reef ecosystem. We focus on *Baculogypsina sphaerulata* as a major sand producer, and address the development of aquaculture techniques for the species. To establish the techniques, a method for rearing juveniles and a convenient method to estimate condition of rearing individuals are needed. First, we measured chlorophyll a content, respiration, and photosynthesis of *B. sphaerulata* individuals to quantify relation between these internal (physiological) conditions and external traits such as body surface color and body mass. When body color of a microscopic image of *B. sphaerulata* was expressed in CIEL*a*b* color space, a* and b* components were correlated with chlorophyll a content. In contrast, L* component was correlated with the maximum photosynthetic rate and initial photosynthetic efficiency. These results indicate that body surface color is useful for estimating internal condition. Second, substrate type (natural algae and artificial algae) and sediment contents (with and without sand) were examined to understand suitable rearing condition for juveniles. When the combination of natural green alga and sand were used as substratum, we were able to maintain juveniles for 51 days with a high survival rate (>90%), without water exchange. However, it was also revealed that the photosynthetic level of individuals under the rearing condition was lower than that of field individuals by the estimation using body color.

15F Benthic foraminifera on coral reefs
Tuesday 10 July, 1215, MR3

Discrimination of benthic foraminiferal assemblages and biotopes from the Capricorn Group, Great Barrier Reef, Australia

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Effective assessment of reef health stems from the investigation of modern biotic communities, in this case marine foraminifera, within a given area. Foraminiferal species diversity, distribution, and their abundance, given the environmental preferences of each species, can reveal much about the reef and the relations that exist between physical parameters that govern an area and the biotic communities that inhabit these areas. Understanding modern foraminiferal assemblages and the parameters that govern them enables the anticipation of change (i.e. brought on by anthropogenic and natural influence) when these parameters are altered. The detrimental impact of change may then be lessened with effective management. Baseline modern foraminiferal data from shallow water tropical carbonate environments of the Capricorn Group (CG) at the southern Great Barrier Reef (GBR) are analysed using a range of quantitative techniques, including Bray-Curtis Q-mode cluster analysis, Multi-Dimensional Scaling (MDS), Fisher ± Index diversity values, and Shannon-Weiner values. Three distinct assemblages of benthic foraminifera and one sub-assemblage are recognised across the four sampled reefs that are correlated with water depth, energy regime, and substrate type. The distribution of assemblages is compared to grain size, algal distribution, live foraminiferal distribution, and diversity indices to isolate the main ecological factors determining foraminiferal distribution within the area.

15F Benthic foraminifera on coral reefs
Tuesday 10 July, 1245, MR3

Impact of metal exposure in the symbiont-bearing foraminifer *Amphistegina lessonii*

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Ca^{2+}-ATPase activity was evaluated in whole adults of *Amphistegina lessonii*. Foraminifer and seawater samples were collected at sites located inside (Porcos Bay-POR, Dois Irmãos Shoal-LDI and Buracão-BUR) and outside (Santo Antonio Harbor-PSA and Biboca Beach-BIB) the 'Fernando de Noronha' Marine National Park (FNMNP) (northeastern Brazil). Individuals from BUR site were also transferred alive to the laboratory and exposed to Zn (0, 25, 42, 68 and 93 µg dissolved Zn/l). Ca^{2+}-ATPase activity was measured in both field and laboratory collected individuals. Higher enzyme activity was observed in foraminifers collected inside the FNNMP. The highest activity was observed in LDI foraminifers (7.4±1.4 mmol P_i/mg protein/min), whereas those collected at the BIB site showed a significantly ($p<0.01$) lower activity (0.7±0.3 mmol Pi/mg protein/min). Metal (Cd, Cu and Zn) concentration in seawater samples were strongly and negatively correlated to Ca^{2+}-ATPase activity. In laboratory-exposed individuals, Ca^{2+}-ATPase activity increased at 25 µg Zn/l, but was inhibited at Zn concentrations higher than 42 µg Zn/l, reaching an activity as low as 0.12 ± 0.02 mmol P_i/mg protein/min ($p<0.01$; $r^2=0.97$). Some metals are known to inhibit Ca^{2+}-ATPase activity, and consequently calcium uptake. Ca^{2+}-ATPase plays a significant role in calcification. Therefore, its inhibition would negatively affect this process in symbiont-bearing foraminifers, resulting in more fragile tests and consequently more vulnerable individuals to increasing threats arising from global changes and ocean acidification. Our results indicate that whole-body Ca^{2+}-ATPase activity is a good biomarker of metal exposure, allowing the detection of local stressors and implementation of management directives for coral reefs preservation.

15F Benthic foraminifera on coral reefs
Tuesday 10 July, 1230, MR3

Provinciality and spatial variability in large benthic foraminifera assemblages

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Large benthic foraminifera are increasingly used for assessing and monitoring quality of the ambient environment. However, many aspects of geographic variability in both taxonomic composition (provinciality) and environmental tolerance remain understudied. Here, I present a review of the assemblage structure in more than 25 areas scattered over the tropical Pacific Ocean. Despite the heterogeneity of data collection, clear patterns emerge. New techniques to assess the ultrastructure of foraminiferal test confirm insights from traditional observations that in several families, many more species are present than previously thought. Overall, this confirms a pattern with two provinces, one in the Southern Pacific and especially the Coral Sea, and the other in the Northern Pacific. A marked variability in assemblage structure was also observed between these provinces, especially in the shallowest, reef flat, and

deepest reef base and inter reef environment. The Trophic Resource Continuum model already predicted an increased partitioning in oligotrophic environments, and this is observed in inter reef assemblages. However, a strong faunal break between nearshore turbid water assemblages and off shore clear water assemblages became apparent as well. New insights show that the reef flat assemblages also exhibit a differentiation between coastal and oceanic settings, even though the location of this faunal break differs from that in the inter reef environment.

15F Benthic foraminifera on coral reefs
Tuesday 10 July, 1130, MR3

Effects of temperature and nutrient stress on symbiont-bearing benthic foraminifera from the Great Barrier Reef

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Physiological responses of temperature and nutrient stress were studied on larger benthic Foraminifera (LBF) hosting endosymbiotic diatoms and dinoflagellates. *Amphistegina radiata* and *Heterostegina depressa* were exposed to increasing temperatures in static temperature experiments (23°C to 33°C, 6 d). In all species photosynthetic activity (measured with a pulse-amplitude modulated fluorometer), chlorophyll *a* content (a proxy for symbiont biomass) and motility (a proxy for overall fitness of the foraminifera) was reduced at 32°C to 33°C and cytoplasm color changes associated with bleaching were observed. A 30 d flow-through experiment at 3 temperature levels (26°C, 29°C, and 31°C) and 3 levels of inorganic nitrate concentration confirmed negative effects of temperature at 31°C for *A. radiata*, *Marginopora vertebralis* and *H. depressa*. Experimental nitrate addition significantly reduced growth and increased mortality in *M. vertebralis*, however, no effect was observed for the 2 other species. This suggests that temperature and nutrient effects are species specific. Our results indicate that temperatures >30°C stress the foram-diatom endosymbiosis in some LBF species, and that this stress appears to lead to bleaching of the host. Given that a 2-3°C increase led to rapid bleaching of most species we propose that, similar to corals, these species are threatened in their typical habitat by near-future sea surface temperature increase and nutrient runoff predicted for tropical reef waters.

15F Benthic foraminifera on coral reefs
Tuesday 10 July, 1200, MR3

Theme 16. Microbes & viruses

16A Microbial mutualism in coral reef invertebrates

Scent of a partner: responses of *Symbiodinium* to coral cues

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Most reef building corals acquire their initial complement of microalgal symbionts (*Symbiodinium*) from the environment. Despite the fundamental nature of the symbiosis, the manner in which the coral and algal partner come together during initial contact remains poorly understood. Both partners have motile life stages but after a short larval period corals become sessile while *Symbiodinium* cells potentially remain motile in the environment and thus may have a continuous window to find suitable hosts. We explored the responses of motile *Symbiodinium* cells to a variety of extracts from inorganic and organic sources including symbiotic and aposymbiotic sources. Using capillary assays to quantify algal cells challenged with these extracts, we detected positive chemotaxis towards extracts from aposymbiotic sources as well as some organic sources and nutrients. For example, the number of *Symbiodinium* cells was over 5 times higher in capillaries containing extracts from apoysmbiotic coral larvae or juveniles than in control capillaries containing only seawater. In contrast, capillaries containing extracts from symbiotic corals did not differ in the number of cells relative to control capillaries. Details on the chemistry of compounds attracting *Symbiodinium* will be provided and the results will be discussed in the context of chemotactic cues leading to the initial contact involved in the establishment of the coral-algal symbiosis.

16A Microbial mutualism in coral reef invertebrates
Thursday 12 July, 1515, MR3

The microbiome of *Galaxea fascicularis* gastric cavity and its importance for coral health

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All corals have a common structure: two tissue layers enclose a lumen, which forms the gastric cavity. Like other animals, corals are likely reliant on their gut microflora to cycle essential nutrients and remove waste products. In this study we sampled the internal fluid of living coral and determined the diversity, structure, and metabolic capacity of the microbial community within the gut of the coral *Galaxea fascicularis* along with the parameters that may shape this community (oxygen, pH) and the chemical characteristics (alkalinity, nutrients concentrations). The coral gastric cavity has distinct chemical characteristics with respect to dissolved O_2, pH, alkalinity, and nutrients (vitamin B12, nitrate, nitrite, ammonium, and phosphate) and therefore may be described as a semi-closed system. Dissolved O_2 shows low concentrations in the deepest parts of the cavity, creating a compartmentalized, anoxic environment. The pH is lower in the cavity than in the surrounding water and shows day/night variations different from those of the surrounding water. Nutrient concentrations in the cavity are greater than the concentrations found in reef waters, especially for phosphate and vitamin B12. The source of these nutrients may be internal production by symbiotic bacteria and/or the remineralization of organic matter ingested or produced by the corals. The importance of the bacteria inhabiting the gastric cavity is supported by the finding of a high bacterial abundance, a specific bacterial community with a high metabolic diversity. These findings open a new area of research that may help us to understand the processes that maintain coral health.

16A Microbial mutualism in coral reef invertebrates
Thursday 12 July, 1645, MR3

Microbial communities associated with different developmental stages of *Pocillopora damicornis*

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Pocillopora damicornis is a reef-building coral that reproduces by a process called brooding: eggs are retained within the maternal polyp, where they are fertilized and eventually released to the water column as developed larvae. In this study, we examined adult, larval, and juvenile life history stages of *P. damicornis* in order to characterize their associated microbiota. In particular, we sought to investigate the acquisition, specificity, and diversity of *P. damicornis*-associated microbial communities using a small subunit ribosomal RNA phylogenetic marker gene-based approach. Multivariate analyses of terminal restriction fragment length polymorphisms of ribosomal RNA genes were used to compare the different *P. damicornis* life stages, which

were sampled in both the subtropical North Pacific Ocean on the island of Oahu, Hawaii, USA, and in the South Pacific Ocean on the island of Moorea, French Polynesia. Preliminary analyses indicate that microbial communities differ between adults and the early life history stages of their offspring (larvae and juveniles), and that the *P. damicornis*-associated microbial communities at all life stages are distinct from the bacterial community composition of the surrounding seawater.

16A Microbial mutualism in coral reef invertebrates
P155

Counting viruses and prokaryotes in coral mucus

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Coral reefs are amongst the most vulnerable marine environments and have declined dramatically over the last 30 years owing to the combined effect of global warming and increasing anthropogenic pressure. An emerging hypothesis proposes that these disturbances could deeply alter the structure and functions of viral and bacterial communities inhabiting the coral surface microlayer, leading in turn to the disruption of the microbial equilibrium and consequently to disease and death of the coral. However, these processes are difficult to study due to a lack of a standard procedure for extracting and enumerating viruses and prokaryotes from the mucus, principally owing to the viscosity and natural autofluorescence of this matrix. In the aim to overcome this methodological issue, we tested 6 protocols based on chemical (methanol, potassium citrate, sodium pyrophosphate, tween 80), mechanical (power homogenization) or enzymatic (trypsin) treatments. Seven cultured coral species were sampled (genera: *Alveopora, Favia, Fungia, Heteroxenia, Lobophyllia, Platygyra, Turbinaria*). The highest efficiencies for bacterial and viral extraction were obtained from protocols requiring (i) potassium citrate for viruses, and (ii) the enzyme trypsin for bacteria. Using these procedures, we showed that both types of particles were more numerous in the mucus than in the overlying water, and that there is substantial variability in their abundance and community structure among coral species. This suggests that the coral surface microlayer is a unique biotop where viral and microbial processes might be host specific and fundamentally different from those observed in the water column.

16A Microbial mutualism in coral reef invertebrates
P156

Photosynthetic symbiosis drives bacterial associations in Great Barrier Reef invertebrates

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Coral reefs are habitat for an array of marine invertebrates that host symbiotic microbial communities. This study applied a 16S rRNA gene pyrosequencing approach to investigate the bacterial diversity of 16 common GBR marine invertebrate species. Samples represented 5 different invertebrate families and included both photosymbiont hosting species (*Symbiodinium* and diatom symbionts) and non-photosymbiont bearing (or symbiont barren) species. All samples were dominated by Proteobacteria, though the composition of microbial communities differed between invertebrate species with and without photosymbionts as assessed by a transformed distance-based-RDA and PERMANOVA ($P < 0.001$). Dominant sequence tags in the photosymbiont bearing invertebrates were affiliated with Spongiobacteria which has previously been implicated in the metabolism of the abundant organic sulfur compound DMSP in corals. Non-photosymbiont invertebrates were dominated by a number of sequences including Sphingobacteria affiliates. Species richness, equitability and phylogenetic tree branch length did not differ between invertebrate species with and without photosymbiont partners ($P > 0.05$; linear regression). This indicates that the number of species, evenness and phylogenetic dispersal in the microbial community (Alpha-diversity) was not influenced by the presence or absence of symbiont, however the species composition (Beta-diversity) was. This study highlights the complex nature of invertebrate holobionts and confirms the importance of photosymbionts in structuring invertebrate-associated bacterial communities.

16A Microbial mutualism in coral reef invertebrates
Thursday 12 July, 1500, MR3

Diazotrophs associated with an endemic Hawaiian coral, Hawai`i

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The paradox of the reef "high productivity and biodiversity in oligotrophic waters" was traditionally attributed to the two-party symbiosis between *Symbiodinium* and host reef organisms, such as corals. However, with further characterization of microbial symbionts in corals, diazotrophic bacteria have been identified as a potential source of inorganic nitrogen available to *Symbiodinium*, in addition to what is provided by the host. Diazotrophs are bacteria and archaea that convert abundant but biologically inaccessible dinitrogen to biologically available ammonium. Diazotrophs have been identified in the tissue of several coral species in Hawaii, but their diversity and identities are not yet fully understood. Hawaii Island offers a unique place to study coral-associated diazotrophs as nutrient-rich groundwater differentially discharges into the coastal marine environment. This could act as a selective pressure, shaping diazotroph communities, especially in light of the potential cost of symbiotic relationships to the host. In this study, diazotrophs isolated from the endemic Hawaiian coral, *Montipora capitata*, were identified by targeting the nifH DNA sequence that codes for a subunit of nitrogenase, the enzyme responsible for nitrogen fixation. The nifH sequence diversities recovered from replicated coral colonies from Pohue, Wai O' Pae and Leleiwi, 3 sites differing in groundwater input on Hawaii Island, were compared. Bacterial groups identified included cyanobacteria, α-, ß-, γ-, and δ- proteobacteria. Though many sequences from within sites were more closely related than those among sites, variable results suggest that presence of groundwater alone does not determine symbiotic diazotroph communities.

16A Microbial mutualism in coral reef invertebrates P157

Worldwide comparison of microbial diversity patterns in five low microbial abundance (LMA) sponges

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Considered to be one of the most ancient multicellular organisms, sponges (Porifera) have numerous qualities that make them singularly well adapted to living in many geographically and ecologically distinct regions. It is hypothesized that the sponges' association with microbial symbionts has contributed to their global propagation in varied ecosystems. Sponges are generally grouped into clusters based on two different lifestyle strategies, those with a high microbial abundance (HMA) and those with low microbial abundance (LMA). Over the past 10 years, a large amount of research has been conducted characterizing the diversity and patterns of microbial communities in HMA sponges, but until now, there has been no systematic comparison of microbial diversity in LMA sponges. In this study, we have characterized and compared the microbial communities of 5 globally distributed sponges: *Stylissa carteri* and *Crella cyathophora* from the Red Sea (Saudi Arabia), *Raspailia topsenti* from the Pacific Ocean (New Zealand), and *Callyspongia vaginalis* and *Niphates digitalis* from the Caribbean Sea. TEM imaging confirms that they are LMA sponges. 16S rRNA gene sequences and phylogenies constructed from this data reveals that while there are minor differences in bacterial phyla associated with LMA sponges, the core community of the organism is consistently dominated by Proteobacteria, Cyanobacteria, and Bacteroidetes. Indicator microorganisms typically found in HMA sponge, such as the Poribacteria and Chloroflexi are missing in the investigated LMA sponge species. We are currently comparing the functionality of HMA and LMA sponges to determine how and why the sponge interacts with this core microbial community.

16A Microbial mutualism in coral reef invertebrates Thursday 12 July, 1530, MR3

Microbial consortia of temperate gorgonian corals

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Due to its location relative to coastal upwelling systems, marine ecosystems of southern California are currently experiencing the effects of ocean acidification. Increasing evidence indicates that changes in pH and temperature can significantly alter coral-associated microbial diversity and metabolism, which in turn affects coral health. However, the majority of this knowledge has come from studies with scleractinian corals. In an effort to better predict the effects of ocean acidification and increasing ocean temperatures on temperate coral health, we explored the relationship of *Muricea californica* with its holobiont under *in situ* and laboratory conditions altering temperature and pH to better understand the physiological roles of the microbial associates. Our results provide important ecological information for less-studied, but ecologically important temperate corals.

16A Microbial mutualism in coral reef invertebrates Thursday 12 July, 1745, MR3

Microbial assemblages of *Acropora palmata* during bleaching and disease events

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Research investigating microbial communities of the coral mucus layer is relatively new; metagenomic analyses have shown a species-specific nature of coral-microbial assemblages. Microbial communities found in coral mucus are believed to act as a primitive immune system protecting coral from potential pathogens. Furthermore, disturbance (natural, anthropogenic, or experimental) of the microbial community found on corals' mucus layer has been shown to result in coral mortality. This study examined microbial assemblages of the critically threatened Caribbean coral *Acropora palmata*. Using high-resolution 16S rRNA tagged pyrosequencing, we investigated spatiotemporal dynamics of microbial community structure during normal conditions, white-pox disease outbreaks, and a severe bleaching event. Additionally, we used 3 years of fate-tracking surveys to monitor changes in coral colony tissue and mortality. These findings document microbial community heterogeneity and allow us to investigate how coral disease and bleaching simultaneously influence microbial assemblages and coral survivorship. We provide new insights into the synergistic effect of multiple stressors and world-wide decline of corals.

16A Microbial mutualism in coral reef invertebrates
Thursday 12 July, 1630, MR3

Corals form specific associations with diazotrophic bacteria

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The complex symbiotic relationship between the coral animal and its dinoflagellate partner (*Symbiodiunium*) is believed to be sustained through a close association with mutualistic bacterial communities that are able to fix nitrogen (diazotrophs) and contribute to the requirements of the holobiont. In this study, we investigated the diversity of the diazotroph bacterial communities associated with 3 common coral species (*Acropora millepora, Acropora muricata* and *Pocillopora damicormis*) from 3 mid-shelf locations of the Great Barrier Reef (GBR) through profiling the nifH fragment of the dinitrogenase gene. The diazotrophic community diversity was also compared between coral tissue and mucus microenvironments plus the surrounding seawater. Our results revealed that corals harbour diverse nifH phylotypes that differ between the coral habitats of tissue and mucus. Coral mucus nifH sequences displayed high heterogeneity with sequences belonging to 5 bacterial classes and overlapping with some bacterial groups found in seawater. Moreover, coral mucus diazotrophs were neither specific to coral species nor to reef locations, reflecting the ephemeral nature of coral mucus. In contrast, the same dominant diazotrophic bacteria were maintained in all 3 coral species tissues and were closely related to the bacterial group Rhizobia, which represented 71% of the total sequences retrieved from tissue samples. Additionally, our results highlighted that coral tissue diazotrophic bacteria were species specific further supporting the coral holobiont principal of conserved bacterial groups associated with coral. Like in terrestrial plants, coral Rhizobia could maintain a close relationship with corals and particularly with the nitrogen-deficient microalgae (*Symbiodinium*).

16A Microbial mutualism in coral reef invertebrates
Thursday 12 July, 1715, MR3

The abundance and diversity of viruses in soft coral tissue

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Coral virology is a newly emerging field of research where the majority, if not all, of the studies published so far focused on hard corals due to their importance in the reef formation. No studies are available regarding the virology of the soft corals despite the latter ecological and economic importance. Therefore, the current study provided the first record for investigating viruses in soft corals tissues. Viral-like particles (VLP) associated with the tissue of *Junceella juncea*, *Carijoa* sp., *Echinomuricea* sp. b., *Euplexaura* sp. and an unknown soft coral, collected from inshore and offshore reef systems south of Kuwait on different seasons, were studied using different methods. The results of the epifluorescent microscope proved the presence of high number of VLP in the soft coral tissues as well as in the seawater and sediment samples from the vicinity of the soft coral colonies. Round and polyhedral shape VLP with sizes ranging between 20-180 nm were detected in the

gastrodermis, coenenchyme, mesentry and tentacles of soft corals using Transmission Electron Microscope. In addition, different bacteriophages were isolated using plaque assay from the tissue of the unknown soft coral, *Junceella juncea*, *Echinomuricea* sp. b. and their nearby seawater and sediment. The bacteriophages found targeting two different Vibrio isolates that were isolated from the soft coral tissues themselves. The isolated bacteriophages were morphologically similar to members of Cystoviridae, Plasmoviridae, Inoviridae and Pocoviridae families.

16A Microbial mutualism in coral reef invertebrates
Thursday 12 July, 1700, MR3

Comparative metatranscriptomics of Red Sea sponge symbionts

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Marine sponges (phylum Porifera) are ancient metazoans with a fossil record dating back to the Precambrian times, and they are also among the most prominent and abundant taxa in tropical reef environments. Sponges are sessile filter-feeders, whose diet is composed mainly of prokaryotic and eukaryotic microorganisms. Depending on diversity and abundance of symbiotic microorganisms in the mesohyl, marine sponges can be classified as low microbial (LMA) or high microbial abundance (HMA) sponges. Here, we present a comparative metatrascriptomic analysis of prokaryotic communities of the Red Sea sponges *Stylissa carteri* (LMA) and *Xestospongia testudinaria* (HMA). The sponge specimens were collected in triplicates and processed in parallel. Prokaryotic messenger RNA was isolated from total RNA with a combination of rRNA and polyadenylated RNA subtractions. In order to explore the active taxa of the sponge-associated microbial community, the V4 and V5 regions of 16S rRNA were amplified from total cDNA. Nucleic acids were sequenced with 454 and Illumina next generation sequencing technologies. Here, we present new metatranscriptome-based insights into the metabolic capacities and the functional repertoire of marine sponge symbionts.

16A Microbial mutualism in coral reef invertebrates
Thursday 12 July, 1545, MR3

Associated bacterial communities of *Seriatopora hystrix* across ecotypes and environments

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The coral holobiont is comprised of both prokaryote and eukaryote members: the coral host; endosymbiotic unicellular alga *Symbiodinium*, and diverse microbial communities including archaea, bacteria, fungi, and viruses. Although a high degree of specificity can exist between these different members of the holobiont, little is known about the level of specificity of bacterial communities in relation to the genotype of the coral host or the *Symbiodinium*. Bacterial communities have been found to be associated with the ability of their coral host to respond to environmental change, periods of stress, and their susceptibility to disease. Here, we assess the bacterial communities (determined using 16S PCR-DGGE) in relation to different genotypes of *Seriatopora hystrix* host (determined using a mtDNA marker and microsatellites) and *Symbiodinium* (determined using ITS2 PCR-DGGE), and across a range of different reef habitats. To explore these associations and the individual contributions of host-*Symbiodinium* genotypes and the environment ,we also conducted a long-term reciprocal transplantation experiment across different environments. In contrast to the clear associations between particular host and *Symbiodinium* genotypes, the diversity of bacterial communities is considerably more complex. However, clear patterns of specificity between the 3 symbiotic partners could be identified, as well as some degree of environmental-specific variation. This study highlights the importance of a holistic approach when it comes to studying the ability of corals to thrive in a wide range of environments and to cope with rapidly changing environmental conditions.

16A Microbial mutualism in coral reef invertebrates
Thursday 12 July, 1730, MR3

Bacterial communities associated with healthy *Montipora capitata*

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Montipora white syndrome is a tissue loss disease that has emerged in Kaneohe Bay, Oahu, that affects the Hawaiian reef coral, *Montipora capitata*. *Montipora capitata* occurs in two color morphs, red and orange, which harbor different zooxanthellae clades and differ in abundance and disease susceptibility on reefs. The red color morph is numerically dominant on reefs yet the orange morph has the highest MWS prevalence. The mucus-associated bacterial community may play a role

in disease resistance in corals and could vary between orange and red coral morphs. Hence, we compared the bacterial communities associated with healthy red and orange morphs of *M. capitata*. Bacterial isolates were cultured on GASW from 5 red and 5 orange *M. capitata* fragments and identified using the 16S rRNA gene (n=119 isolates from red morph and n=48 isolates from orange morphs). Nine bacterial genera were found on red morph fragments and eight genera on orange morph fragments. The bacterial communities overlapped with 5 genera found in both color morphs (*Alteromonas, Pseudoalteromonas, Psychrobacter, Erythrobacter*, *Vibrio*). However, the abundance (% of identified isolates) of some overlapping genera varied between morphs. Red morphs had a higher abundance of *Alteromonas* sp. (53% vs. 40%) and *Vibrio* sp. (18% vs. 2%) whereas orange morphs had a higher abundance of *Psychrobacter* sp. (23% vs. 2%). There were also bacterial genera apparently unique to each morph. We are currently investigating the uncultivable bacteria associated with coral tissue to provide better resolution of the resident and transient bacterial communities in healthy colonies.

16A Microbial mutualism in coral reef invertebrates
P159

Response of *Cinachyrella*'s bacterial community to oil contamination

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Marine sponges are essential components of benthic and coral reef ecosystems, providing shelter and nutrition for many organisms. Furthermore, sponges can filter a large quantity of water (up to 24,000 L of water kg^{-1} day^{-1}) and thereby influence their environments. These characteristics make sponges remarkable environmental sentinels of reef health. Many sponge species harbor a high diversity and abundance of microbes (Archaea, Bacteria and Eukaryotes) which constitute up to 40% of the total sponge biomass. Bacteria abundance in sponge tissues can be two- to four-fold higher than concentrations in the surrounding seawater. Furthermore, some bacteria permanently inhabit the sponge tissues while others are rapidly consumed. As part of a larger study to evaluate the effects of the Deepwater Horizon oil spill on marine microbiota, we investigated the bacterial community of the sponge *Cinycharella*. 16S rDNA tag pyrosequencing was used to assess the bacterial diversity in: a) wild *Cinachyrella* and b) specimens kept in tanks for up to 4 weeks after collection. Additionally, we explored the rapid response (24h) of the bacterial community in sponges subjected to oil; dispersant; and oil + dispersant treatments. Results showed that wild sponges had the highest bacterial diversity with many taxa being present. As time progressed, the diversity in captive specimens was reduced, and the community was dominated almost entirely by Alpha-, gammaproteobacteria and Actinobacteria, while cyanobacteria almost disappeared. The oil and dispersant treatments dramatically altered the species' composition as well. These results will help understand the response of sponges' bacterial community to anthropogenic disturbances.

16A Microbial mutualism in coral reef invertebrates
P158

16B Coral-microbe interactions & disease

Potential factors affecting patterns of black band disease on a reef in Guam

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Spatial patterns of coral disease on reefs can provide clues to differential susceptibility between coral host species and other factors that may affect disease processes. We examined the distribution of a chronic black band disease (BBD) infection on a reef in Guam and found that, while numerous coral genera susceptible to BBD were found within transects, only one coral, *Goniopora fruiticosa*, was infected with the disease (mean 4-year prevalence: 11.8%). This suggests that *Gonipora* is more susceptible to BBD than other species present and so we examined factors that could affect disease establishment. Manipulative studies found the innate susceptibility of *Gonipora* to BBD was high but not different from *Porites cylindrica*, the most common coral within transects. BBD successfully infected four out of five *Goniopora* fragments and all *Porites* fragments (n=5). Similarly, direct BBD transmission was successful whether the disease was transferred between *Goniopora* fragments or to a *Porites* fragment. To examine the role of fish as vectors of BBD or, alternatively, as preferential feeders on the BBD band, we examined the foraging choice of two generalist corallivores, *Chaetodon lunulatus* and *C. reticulatus*. Little foraging was observed on *Gonipora* by either fish species (mean <5 bites/30min test) and instead both fish species fed predominantly on *Porites*. The pattern of BBD infection observed in *Goniopora* on this reef may be due to high innate vulnerability to infection combined with a

lack of fish predation, allowing BBD to establish and remain on colonies as well as decrease disease transmission to other species.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1115, MR3

Bacterial profiling of White Plague Disease in multiple coral species

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Coral disease can heavily impact reef health and has reduced live coral cover by up to 80% in some places. With the advent of novel molecular techniques such as next generation sequencing, we are well aware of the high diversity and specificity of coral-associated bacteria. However, only a few studies have looked at changes within the bacterial community of corals as a consequence of disease. Furthermore, most studies have focused on microbial profile shifts of a specific coral species that suffers from a specific disease. Examining only one coral species at a time might not paint an accurate picture of how the assemblage of coral-associated microbes changes in response to disease. Here, we aim to apply an integrative approach to the study of White Plague Disease (WPD) by analyzing microbial profiles of different coral species from different oceans (i.e. Gulf of Thailand and the Caribbean). We used 16S PhyloChip assays to compare bacterial community changes of healthy and diseased samples within and between these coral species. The PhyloChip assay is a microarray-based method that identifies and measures the relative abundance of more than 65,000 individual microbial taxa. With this approach we hope to gain a deeper understanding of the etiology and bacterial footprint of WPD by identifying key bacterial species that change as a consequence of disease.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1145, MR3

Water quality effects on *Montastraea* spp. associated bacteria in USVI

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The objective of this study was to describe and quantify the microbial community composition associated with the mucus of the *Montastraea annularis* species complex, the major framework building species (50-80% of total coral cover) of corals in the U.S. Virgin Islands region. Coral reefs in the region are greatly impacted by various kinds of anthropogenic stress and there is a trend of decreasing coral cover and health across a nearshore to offshore stress gradient. The microbial community found in coral mucus forms the primary line of defence against pathogenic invasion and it has been suggested that changes in the physical and chemical properties of sea water can cause changes in their populations, potentially making corals more susceptible to diseases. To understand whether the mucus-associated microbial community composition changed with the proposed water quality gradient, mucus samples were collected from corals in nearshore, shallow (<30 m) and highly impacted reefs as well as offshore, shallow and relatively pristine reefs. Samples were analyzed using 16S rDNA technique for patterns of change in microbial composition across the above mentioned gradient. Preliminary results suggest that the microbial population is dominated by members of the class ß-Proteobacteria being the most abundant in all the samples. Soil related bacteria and pathogenic bacteria were isolated from the nearshore impacted reefs but not offshore pristine reefs. Further statistical analysis will help in understanding whether the microbial community composition changes as one moves across this proposed water quality gradient, and whether this change is associated with coral health.

16B Coral-microbe interactions & disease
P160

Microbes from corals and a coral predator, Saint Paul's Archipelago

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Reef corals host diverse bacterial populations as stated by culture and culture-free methodologies. This diversity often includes many novel species and is crucial to vitality of reef environments. However, environmental stress factors determine shifts in the microbiota abundance and composition which compromise corals' health. More than 20 coral diseases

have been described, but etiological agents are characterized for only 6. The best understood case is bleaching of *Oculina patagonica* by *Vibrio shiloi* (= mediterranei), where the polychaete *Hermodice carunculata* (fireworm) is the bacterial reservoir and vector. Aiming to perform the first taxonomic survey of coral associated bacteria from St. Peter and St. Paul Archipelago (Mid-Atlantic Ridge, Brazil) we characterized the culturable microbiota associated with the hermatypic species present there - *Scolymia cf. wellsi, Madracis decactis* (healthy and 'bleached') - and *H. carunculata*, observed preying on *M. decactis* colonies. The Archipelago is a pristine area, 1.100 km from the coast (00°56'N, 29°22'W). Gene sequences of 16S rRNA and pyrH were employed for taxonomy and phylogenetic analysis. Four hundred two isolates were obtained (*Scolymia cf. wellsi*: 79, *M. decactis*: 115, *M. decactis* 'bleached': 51 and *H. carunculata*: 157) and the main groups identified are *Vibrio, Photobacterium, Pseudoalteromonas, Pseudovibrio* and *Bacillus*. Strains of *Vibrio* (A-96, A-103, A-110) may represent a novel species related to V. *variabilis*. The dominant taxa belonged to the *Vibrio* core group (e.g. *V. harveyi*) and *V. shiloi*. Most of the strains isolated from the fireworm are *V. shiloi* (n>100), corroborating its role as reservoir and vector of the coral pathogen.

16B Coral-microbe interactions & disease
P161

Model system for the molecular mechanisms of coral disease

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Tissue loss diseases (white syndromes) in some coral species have been attributed to pathogenic bacteria. However, little is known about the pathogenesis of these diseases. In Hawaii, we have discovered a strain of *Vibrio*, designated OCN008, that was capable of reproducing signs of tissue loss disease in infection trials. Of 15 fragments of *Montipora capitata* in aquaria inoculated to a final concentration of 5 x 103 to 5 x 106 bacteria/ ml, all showed signs of tissue loss between 12 h and 12 d after inoculation. Control fragments remained healthy during this time. In addition to causing tissue loss, strain OCN008 produced a compound extractable from growth medium with methylene chloride that inhibited the growth of bacteria isolated from healthy *Montipora capitata* and a range of other common laboratory bacterial strains. To facilitate the identification of genetic determinants of disease and anti-bacterial activity, strain OCN008 was developed as a genetic system. A broad-host range plasmid was stably maintained in the absence of selection and was used to introduce foreign DNA by conjugation. In addition, strains with apparently random mutations were generated with a transposon. Of 480 transposon mutants screened for their ability to inhibit the growth of a target bacterial strain of the genus *Pseudoalteromonas*, 4 were found to have lost anti-bacterial activity. Methods for site-directed mutagenesis are under development. Strain OCN008 and *Montipora capitata* represent a genetically tractable model system for the investigation of tissue loss diseases in coral.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1745, MR3

Coral mucus inhibitory activity and its role on microbiota structure

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Interest in coral microbiota has recently increased since several works demonstrated its importance on coral health. Corals' surface is covered by a layer of mucus, which plays several roles, such as protection against physical, chemical and biological harm. It has been demonstrated that the mucus microbiota may play a role against microbial pathogens. Recently, studies indicated that under stressful conditions, the mucus can also present antibacterial properties. We have done antagonistic activity assays of sterile mucus against sediment microbiota. For that, GASWA (glycerol artificial seawater agar) plates were treated with sterile mucus of 4 coral species found on São Paulo State coast, *Mussismilia hispida, Madracis decactis, Palythoa* sp, and *Tubastraea* sp., sampled at July 2010 and January 2011. Sediment samples were inoculated on these plates and the number of bacterial colonies, after incubation for 24h at 30°C, was determined and compared with control plates. In addition, we identified 236 bacterial isolates from mucus, surrounding water and sediment, using the V3 to V6 region of the 16S rDNA. We observed a smaller number of colonies in the agar plates treated with coral mucus from *M. decactis*, *Palythoa* sp., and *Tubastreae* sp.. These results with the ones of overlapping between the communities of mucus and the surrounding environment, highlight the role of mucus as a selective agent for bacteria: either by providing different niches or possessing substances that may inhibit the growth of some bacteria found in the environment.

16B Coral-microbe interactions & disease
P162

New reports and expansion of the distribution of Indo-Pacific coral reef diseases in Japan.

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Aside from bleaching, few diseases of corals and other reef organisms have been reported from Japan. This is the first report of lesions similar to *Porites* ulcerative white spots (PUWS), brown band disease (BrB), pigmentation response, and crustose coralline white syndrome (CCWS) for this region. Corals and other reef organisms were carefully checked along 2 reefs in Ooyama, Okinawa and two reefs in Zamami, Kerama Islands, 50 km west of Okinawa in March 2010. Disease prevalence was assessed later along 2 band transects in each reef. Growth anomalies (GA) (8.3%), white syndrome (WS) (4.2%) and BrB (2.3%) were the most prevalent diseases in the Zamami reefs, affecting mostly acroporid corals. Black band (BBD) (6.6%), WS (1.6%), PUWS (12.5%), and an unknown syndrome (7.5%), affecting *Porites, Pachyseris* and *Echinophyllia* species, were the most prevalent in the Ooyama reefs. Mean disease prevalence was higher in Ooyama (6.8 ± 5.7%) compared to Zamami (3.0 ± 3.5%). Pigmentation responses (pink spots and pink lines, discolorations) associated with tissue mortality were observed in massive *Porites, Pachyseris* sp. and tabulate acroporids, Bleaching with associated tissue mortality was observed in the soft coral *Lobophyton* sp. These results and observations suggest a significant expansion of the geographic distribution of PUWS, BrB, pigmentation responses and CCWS in the Indo-Pacific, and indicate that the northern-most coral reefs in the Pacific are susceptible to a higher number of coral diseases than previously thought and that attention to this problem must be addressed.

16B Coral-microbe interactions & disease
P163

Shift of microbial communities between healthy and bleaching *Acropora solitaryensis*

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Serious bleaching events have been observed in *A. solitaryensis*, one of the main species of reef-building coral on Xisha Islands (China) during 2008-2011. Microbial communities of the healthy and partially bleached samples were compared using culture-independent approaches. Denaturing gradient gel electrophoresis (DGGE) analysis showed that except a few minor bands, the major banding patterns are similar among the healthy colonies from different locations. *Psychrobacter* sp., *Rhizobium* sp., *Pseudomonadales* sp. and *Ochrobactrum* sp. that have been reported to fix nitrogen and produce antimicrobial compounds are the dominant species in the healthy colonies but the *Vibrio* species dominate the microbial community in the partially bleached samples, and the intensity of one band identified as *Vibrio coralliilyticus* is heavily increased in the bleached section compared with the healthy part. Two16S rDNA clone libraries were constructed and about 500 clones from each library were selected and digested by HaeIII and XspI. Seventy-one RFLP profiles were identified from the healthy colonies, but only 41 were identified from the partially bleached samples. Concomitantly, the sequences of the clone libraries have also revealed a much higher level of bacterial diversity in the healthy colonies. This study provides further evidence to demonstrate that shift from commensal microbial assemblages to the opportunist pathogenic bacteria is closely associated with the bleaching events of the *Acropora* sp. which has been reported by Bourne et al (2008). However, it needs further investigation to answer the question that the increase of *Vibrio* species is the reason or the consequence of the bleaching events.

16B Coral-microbe interactions & disease
Thursday 12 July, 1035, MR3

Coral reefs harbour new species of the family Vibrionaceae

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The reef biome has a key role for the health of the oceans; furthermore, it is also extremely important for the economy of several countries via fishing, ecotourism and as nursery species place. In the last decade, studies of coral associated microbiota diversity have been increased and have revealed the importance of the microorganisms in the maintenance of the holobiont equilibrium (coral + microbiota +

zooxanthella). *Vibrios* may represent a large proportion of the coral microbiota and it seems to establish different relationships with corals that vary from parasitism to mutualism. On the other hand, much of this enormous bacterial diversity is represented by novel groups which are still waiting formal taxonomic characterization and may have an important ecological role in the holobiont survival. Vibrionaceae family comprises over 129 formally described species distributed in seven genera: *Vibrio, Photobacterium, Salinivibrio, Grimontia, Enterovibrio, Catenococcus* and *Aliivibrio*. In a survey on the diversity of heterotrophic bacteria associated with holobionts in São Paulo, Brazil, several isolates were taxonomically characterized by means of a polyphasic approach, comprising Multilocus Sequence Analysis (MLSA), DNA'DNA hybridizations (DDH), divergence between the thermal denaturation midpoint (Tm), and phenotypic characterization. Based on the polyphasic analyses, we have described 4 new species of *Vibrio* (*V. communis, V. marinus, V. variabilis* and *V. alfacsensis*) and one of *Photobacterium* (*P. jeanii*), confirming that corals are sources for new bacterial taxa discovery. Some new species (e.g. *V. communis*) can fix nitrogen and may play a key role on the host vitality

16B Coral-microbe interactions & disease
P164

Viruses as potential destabilizers of the coral-algal symbiosis

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In one model system (*Chlorella-Chloroviruses*), green algae can resist infection by phycodnaviruses through endosymbiosis within protists. Phycodna-like viral particles are also associated with coral-algal symbioses, based on transmission electron microscopy (TEM) and the isolation of sequences similar to phycodnaviruses from coral species and other cnidarians. To investigate whether phycodna-like viruses target the algal symbionts (genus *Symbiodinium*) of corals, we experimentally induced viral lytic cycles from long-term, mixed *Symbiodinium* cultures of clades A, C, and D. In 2 experiments, cultures were exposed to UV irradiation or maintained as controls (N = 8 total). At 0, 24, 48, 72, 96, and 110 hours after initiation, culture condition was assessed visually and via *Symbiodinium* and viral counts. Cultures were then preserved for TEM or enriched for viral nucleic acids and pyrosequenced. In UV-treated *Symbiodinium* cultures, cell densities declined over the experimental period, and TEM images contained abundant viral-like particles (VLPs). From 10 sequence libraries, 671 unique similarities (e-values<10-12) to known phycodnavirus sequences were detected. Among these were hits indicative of chloroviruses, such as enzymes (GDP-D-mannose dehydratase and fucose synthase) involved in sugar metabolism. Further, analyses of *Symbiodinium* EST libraries identified thousands of phycodna-like gene products. The high abundance of phycodna-like similarities in these libraries and the association of VLPs with algal cells in TEM images strongly suggest *Symbiodinium* spp. are vulnerable to viral infection. If *Symbiodinium* frequently experience such infections, then phycodna-like viruses can significantly impact the algal diversity available to corals and ultimately, the flexibility and/or stability of coral-algal symbioses.

16B Coral-microbe interactions & disease
Thursday 12 July, 1115, MR3

Investigation of a coral disease outbreak within Kaneohe Bay, Oahu

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Montipora white syndrome (MWS) is a tissue loss coral disease which, as shown in prior studies within Kaneohe Bay, Oahu, results in slow, progressive tissue loss in the common reef coral, *Montipora capitata*. In March 2010, an outbreak of an acute phase (rapid tissue loss) of the disease was discovered in Kaneohe Bay, and Hawaii's newly developed multi-agency Rapid Response Team was dispatched to investigate. Rapid visual surveys on snorkel found the outbreak occurred predominantly in the southern end of Kaneohe Bay (n>200 cases), with the central and northern parts of the Bay having few cases (n=7 cases). Twenty-three colonies and 5 clusters of the disease with acute MWS were tagged and followed through time. The acute phase of MWS was found to be extremely virulent, with numerous colonies suffering complete mortality within weeks. Histology found the predominant microscopic lesion was segmental ablation of upper body wall, wound repair, and necrosis of mesenterial filaments and gastrodermis, particularly upper body wall. Belt transects were surveyed during the outbreak at 12 semi-permanent sites around Coconut Island, Kaneohe Bay, and an average of 0.05 (SE+0.01) cases of acute MWS/m^2 *M. capitata* were documented (total=51 cases). This was significantly higher than the historical level of acute MWS at these same sites in 2006

(total=0 cases). A follow-up survey at the same 12 sites in 2011 found an average of 0.03 (SE+0.01) acute MWS/m^2 *M. capitata* (total=28 cases). This suggests that this disease is now a more common component of the ecosystem within Kaneohe Bay.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1415, MR3

Transcriptomic landscape of the coral holobiont in White Plague Disease

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Pyrosequencing studies on scleractinian corals have primarily focused on surveying healthy specimens or those exposed to laboratory treatments of various abiotic stressors (i.e. temp, pH, DOC, and other nutrients). Few studies have applied these next generation techniques in corals, as it pertains to disease. Biological agents that affect multiple coral species are of particular interest to understand compositional and functional changes in the microbiota of the coral holobiont. White Plague Disease (WPD) is described as a bacterial disease, reported to infect over forty coral species, and responsible for epidemics that have caused significant reef decline in the Caribbean. Although a pathogen was confirmed by Koch's postulates for WPD, recent barcoding efforts failed to detect this pathogen in diseased samples. However, drastic shifts in the microbial community were observed. Comparative surveys of the holobiont metabolism and its actively expressed genes might help better understand the WPD infection. Tissue samples and mucus from healthy and WPD-compromised *Montastraea* sp. samples were collected at reef sites off Puerto Rico (USA) to generate parallel metagenomic and metatranscriptomic profiles. We hope to elucidate the genetic potential and gene expression patterns of the coral holobiont involved with pathogenic invasion. This will be the first study to apply tandem pyrosequencing approaches to obtain a global assessment of a coral disease *in situ*.

16B Coral-microbe interactions & disease
Thursday 12 July, 1130, MR3

Disrupting pathogenesis: chemical interference of quorum sensing by Australian Alcyonacea

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Soft Corals, important members of the marine benthos, produce bioactive secondary metabolites and, unlike scleractinian corals, rarely demonstrate signs of bacterial infection. Quorum Sensing (QS), a known mechanism of virulence in pathogenic coral bacteria, triggers virulence through small molecules known as Acyl homoserine lactones (AHLs). AHLs share structural similarities with the dominant bioactive metabolites of soft corals, the cembranolides. We hypothesised that soft corals interfere with QS and potential infection through cembranolide molecules. To this end, the bacterial biosensors *Agrobacterium tumesfaciens* A136 and *Chromobacterium violaceum* CV026, were used to screen extracts of 16 soft coral specimens collected from Orpheus Island on the Great Barrier Reef for their ability to activate or inhibit QS. Eight of the 16 soft corals tested demonstrated interference with QS. The active fractions isolated all contained cembranoid metabolites. Soft corals from the genera *Lobophytum* and *Sinularia* were chosen for further structural investigation. The biosensors were coupled with the chemical separation and structural techniques High Performance Liquid Chromatography, Mass Spectrometry (HPLC-UV-MS) and Nuclear Magnetic Spectroscopy (NMR) to identify the active compounds. Four cembranolide molecules, Isolobophytolide, Lobolide, Flexibilide and Dihydroflexibilide were isolated and tested for for activation of QS. The activity profiles of these compounds reflect the different levels of structural similarity to bacterial QS molecules. Cembranoid compounds may be involved in interactions between a soft coral and its associated microbial community. Further investigation will provide not only an understanding of this interaction, but may also aid in the prevention of bacterially induced diseases.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1700, MR3

Ecological implications of an infectious sponge disease on Caribbean reefs

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Diseases of sponges are being reported with increasing frequency worldwide. Since sponges are essential ecological components of

Caribbean reefs, understanding the dynamics of these diseases is vitally important. *Aplysina* Red Band Syndrome (ARBS) affects sponges of the genus *Aplysina* and is widespread across the Caribbean basin. In the Bahamas, ARBS affects 10-15% of *Aplysina cauliformis*, a dominant member of the Caribbean sponge community. Long-term monitoring of *A. cauliformis* populations on reefs in the Bahamas demonstrates a clumped distribution of ARBS-affected sponges on the reef. Diseased sponges are most frequently found in close proximity to diseased individuals observed in earlier surveys; however, diseased sponges are occasionally found remote from other affected individuals. These observations suggest that contact is a primary mode of transmission but that ARBS must also be transmitted by other mechanisms. Laboratory and field experiments have confirmed that ARBS is highly transmissible. When healthy sponges are placed in contact with ARBS lesions, the lesion transmits to the healthy sponge within days, although the rate of transmission appears to vary with season. ARBS lesions are visually dominated by filamentous cyanobacteria, and these organisms likely play a primary or secondary role in pathogenesis. To date, reinfection experiments using a culture of the cyanobacterium *Leptolyngbya* sp., the dominant cyanobacterium isolated from ARBS lesions, was not successful at initiating an ARBS infection on healthy sponges *in situ*, suggesting that pathogenesis might require a polymicrobial consortium or that alternative vectors might play a role in disease transmission.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1230, MR3

Visualization of coral-associated bacterial respiration using biological oxygen demand optode

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Coral health is reduced when in close proximity to many types of algae. The direct cause of this is still unknown, although it has been shown that zones of hypoxia are generated at the interface of corals and turf algae. We tested the hypothesis that bacteria associated with the species *Montastraea annularis* draw down more oxygen when exposed to organic matter released by turf algal communities than that of crustose coralline algae or coral of the same species, which have not been shown to create hypoxic interfaces. A novel method to measure respiration rates of bacterial communities *in situ* was applied to measure the respiration rates of coral-associated bacterial communities. We used biological oxygen demand (BOD) optode arrays imbedded with bacterial isolates from *M. annularis* to visualize the drawdown of oxygen by the bacteria, both spatially and temporally. Preliminary data show that oxygen drawdown by coral-associated bacterial communities is increased when organic matter generated by turf algae is introduced. These findings suggest that hypoxic zones at coral-turf algal interfaces are microbially driven, likely due to increased organic matter release from turf algae communities. We also implemented these methods to test the hypothesis that there is a negative correlation between respiration rates of coral-associated bacteria and distance downstream from turf algae.

16B Coral-microbe interactions & disease
P165

Environmental and ecological cofactors of coral growth anomalies in Hawaii

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Growth anomaly is a prominent coral disease in Hawaii, yet its epizootiology remains poorly characterized. Studies have shown that growth anomalies impede various biological and photophysiological functions, highlighting the ecological threat of this disease. Reduced water flow has been correlated to high severity levels of growth anomalies affecting *Montipora capitata* at Waiopae, Hawaii. However, comprehensive examinations of other environmental and ecological parameters that may be cofactors to growth anomaly prevalence and severity have been minimal in Hawaii. This study examined the effects of water quality and community structure on growth anomaly prevalence and severity in all coral species at 6 sites around Hawaii Island. These sites represented a full range of environmental characteristics: embayments to tidepools, and various levels of ground water discharge, human development and traffic, and coral cover. The prevalence and severity of growth anomalies were highest at Kailua Bay for *Porites lobata* ($p<0.05$). Here, the density of *P. lobata* was the most significant factor influencing prevalence and severity of growth anomalies ($p<0.05$). Similarly at Waiopae, density of *Montipora capitata* was the strongest factor positively influencing prevalence and severity of growth anomalies ($p<0.05$). Overall, species density seems to be the key driver for growth anomaly prevalence and severity for each coral species. Water flow and any of the water quality parameters examined could not explain prevalence of growth anomalies. While these findings provide a valuable contribution to the epizootiology of coral growth anomaly,

pathological examination and environmental assessment of habitats are necessary to identifying cofactors of this disease.

16B Coral-microbe interactions & disease
P166

Changes in Seafan and *Montastrea* bacteria in the 2010 event

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Fall 2010 was the warmest year on record at some locations in the Caribbean. Although storms defused some of the warming in the northeastern Caribbean (Puerto Rico and the Virgin Islands) later in the event, and the warmest waters hit the southern Caribbean (Curacao, Venezuela, Columbia) substantial bleaching still occurred in Puerto Rico. We sampled tissues of marked colonies of *Gorgonia ventalina* and *Montastrea faveolata* before and through the event to detect changes in total associated bacteria and the immune transcriptomes. Relative abundance and diversity of bacteria were determined by comprehensive sequencing of 16S rRNA sequences amplified from whole coral extracts and changes in expression of immune and stress related genes were examined with quantitative PCR analysis. Because sea fans have ridden through previous warming and disease events with large resilience and little visible bleaching, we hypothesized that bacterial assemblages associated with sea fans would be different than *M. faveolata* and show less bacterial change (i.e. more resilience) during the heating event.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1245, MR3

Monthly changes in bacterial community structure on *Acropora muricata*

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Interactions between hermatypic corals and bacterial communities on the coral surface play key roles in shaping coral health and disease. Although several species of bacteria, such as those belonging to Vibrionaceae or Alteromonadaceae had been identified as causative agents of coral diseases, recent studies have suggested that dynamics of the surface bacterial community in terms of species composition and metabolism exert considerable impacts on the disease development on the coral. In order to better understand the dynamics of surface bacteria, we aimed to monitor the bacterial community structure on the surface of *Acropora muricata* by DGGE and clone library analyses. In 2010, monthly we collected branches of *A. muricata* from Okinawa Churaumi Aquarium, Japan and PCR-amplified 16S rRNA genes from DNA extracted from the coral specimens. DGGE resulted in the detection of bacterial genera, such as *Acinetobacter* and *Sphingomonas*. Clone library analysis also supported persistent presence of *Acinetobacter* in each month, and revealed occasional presence of other genera, including *Endozoicimonas*, *Spongiobacter* and *Vibrio.* These results demonstrated that bacterial community on *A. muricata* surface was comprised of diverse types of bacteria that may be benign or pathogenic to the coral. Further identification of the bacterial components is clearly needed to gain deeper insights into interactions not only among the bacteria, but also between the bacteria and the coral.

16B Coral-microbe interactions & disease
P167

Long-term study of extremely slow disease syndromes in the Marshall Islands

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A geographically isolated disease outbreak, superficially resembling yellow band disease, was observed in first 2007 on the south central shore of Majuro atoll (Ajeltake) involving many massive corals (predominantly faviids, *Hydnophora,* and *Pavona duerdeni*). *Turbinaria, Scapophyllia* and *Isopora* are also affected by slowly spreading lesions. Massive *Porites* spp. are also in decline here, with distinctly different disease signs. The massive species, *Isopora* and *Turbinaria* had previously become severely depleted or extirpated further to the east, closer to the population center; disease had been documented there in 2003. The geographic range of the Ajeltake outbreak correlates well with local concentrations of human population and nutrient input. Time series analysis of dozens of colonies reveals a spreading rate between 0.1 and 0.4 mm/day, typically with 3-12 lesions on each colony. Disease progression can span 5 years on a single *Hyndophora* microconos colony; in each case mortality is complete. An aggressive species of encrusting algae often colonizes the lesions, and also appears to grow over uninfected colonies, growing at the same rate (mean 0.2 mm/day). Similar, although unitary,

lesions are found on many *Symphillia* colonies, but spreading only .01 mm/day or less. The high disease incidence, up to 80% of the massive population, contrasts with 0% incidence on neighboring atolls with cleaner water. It also suggests that this reef (which has also lost its anemones and most of the formerly dominant *Isopora* colonies) has passed a tipping point, and few massive colonies will survive the decade.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1545, MR3

Towards an epidemiology of colonial organisms

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Rising interest in the disease ecology of highly integrated colonial animals, such as reef corals and sponges, prompts a need for an epidemiology appropriate to these organisms' biology. Current epidemiological work often statistically confounds disease progression with colony size, which, in turn, hampers robust inferences about disease etiology and control. Here, I demonstrate the shortcomings of current measures of disease progression in colonial organisms and provide a size-corrected method derived from plant epidemiology. I argue that realizing the promise of an epidemiology suited to colonial organisms will require development of approaches unique to a colonial life history, in addition to taking greater advantage of the vast analytical toolkit afforded by medical, veterinary and plant epidemiology.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1130, MR3

Using coral disease as a monitoring tool for reef-based recreation

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Although first-hand experience of coral reefs is one of the best ways to promote public awareness of conservation issues, achieving the dual objectives of providing recreational opportunities and preserving natural environments is challenging. Much of what is currently known about the effects of recreational and tourist activities on coral reefs comes from studies of changes in percent coral cover or impacts associated with direct physical damage and breakage. The results of previous studies show that the effects of recreation and tourism activities on corals are few and isolated. However, a variety of human-related disturbances have been associated with elevated levels of coral disease and ongoing tissue loss caused by even slowly progressing diseases, could cause greater levels of coral mortality than immediate but short-term effects associated with localized breakage. In partnership with reef managers and the tourism industry, we conducted coral health surveys at sites with both low and high levels of tourism and recreational activities in Australia and overseas. Our results suggest that coral disease prevalence may represent a useful metric for identifying local impacts associated with human activities on coral reefs. However, spatio-temporal differences in disease prevalence among reefs indicates that a fine scale 'site by site' approach is likely to prove most appropriate for managing disease impacts. In this regard, we suggest determining limits of acceptable change and aiming to keep individual sites within those limits by establishing clear and long-term monitoring protocols, coupled with reactive management strategies that will ensure ongoing conservation of coral assemblages and tourism.

16B Coral-microbe interactions & disease
Thursday 12 July, 0930, MR3

Environmental stress, symbiosis and disease in a coral reef sponge

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Approximately two-thirds of *Ianthella basta* sponge populations from the Great Barrier Reef and Torres Strait show visible evidence of a disease-like syndrome. Symptoms of the syndrome include discolored, necrotic spots, tissue degradation, exposure of the skeletal fibers, and disintegration of feeding cells. To ascertain the role of microbes in the disease process, profiles of bacteria, viruses, fungi and other eukaryotes were compared between healthy and diseased sponges. A very low diversity of microbes was evident with both healthy and diseased sponge communities dominated by 3 strains: an Alphaproteobacteria, a Gammaproteobacteria and a Thaumarchaea. Bacterial cultivation, community analysis by DGGE (bacteria and eukarya), sequencing of 16S rRNA clone libraries (bacteria and archaea) and direct visual assessment by electron microscopy failed to reveal any putative pathogens. In addition, infection assays could not establish the disease in healthy sponges, even after direct physical contact with affected tissue.

These results provide evidence that microbes are not responsible for the formation of brown spot lesions and necrosis in *I. bas*ta. Further manipulative experiments were undertaken to determine the role of environmental stressors (sediment and temperature) in the formation of brown spot lesions. Although sponge health deteriorated under thermal stress, neither elevated temperature nor sedimentation induced brown spot lesions. Overall, the microbial community of *I. basta* remained stable under varying stressors, with the same 3 symbionts always observed. Future work will examine auto-immune dysfunction and senescence in the sponge host by identifying genes that are differentially expressed in sponges displaying disease-like symptoms.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1215, MR3

Microbial activity and dissolved organic matter in Sesoko reef, Okinawa

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Dissolved organic carbon and nitrogen (DOC and DON, respectively) in coral reef waters play a key role supporting the microbial food web. The relationship between DOC, DON, microbial activity, and macro-organisms in reef environment is not well understood. The fate of DOC, DON, and microbial abundances were studied on the fringing reef of Sesoko Island (Okinawa, Japan). Concentrations of DOC and DON increased from day time to evening time (68.5 µM C to 74.1 µM C and 3 µM N to 4.4 µM N) and then decreased (66.6 µM C and 3.4 µM N). Higher microbial activity was shown by gradual increase of bacteria abundance from day time to morning time, due to consumption of organic material derived from reef organisms such as coral (from 7.4 X 105/ml to 13 X 105 /ml). Detectable amino acid concentrations also correlated with microbial abundance (140 nM - 150 nM). These link microbial activity and DOC and DON in reef waters. We suggest that the measurement of DOC and DON in shallow reef water will be an important indicator to describe the interactions between microbial activity and coral stress.

16B Coral-microbe interactions & disease
Thursday 12 July, 1200, MR3

Coral diseases in the central Republic of Maldives

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The coral reefs of the Republic of Maldives are among the most diverse in the Indo-Pacific, but little is known about coral diseases in this archipelago. This study was conducted in the waters of Faafu Atoll and North Male Atoll to identify diseases affecting reef-building corals and to estimate their prevalence on the reef. A total of 12 sites were sampled via 72 belt transects and a total of 12,236 colonies of 15 coral genera were observed between October 2010 and June 2011. Our survey of the Maldivian reefs revealed the presence of white syndrome, brown band disease, skeleton eroding band, ulcerative white spot disease, and black band disease. In the total area surveyed, 10 genera were affected by at least one disease, with a total of 232 scleractinian colonies exhibiting lesions caused by disease. A preliminary comparison of data among the study sites around Magoodhoo Island revealed a higher prevalence of white syndrome in *Acropora* spp. in shallow water compared with deep water. The prevalence of skeleton eroding band in *Acropora* spp. in the shallow sites (1.8 ± 1%) was more than twice that in the deep sites (0.8 ± 0.5%), while the highest prevalence of skeleton eroding band in *Pocillopora* spp. occurred in the deep sites (2.5 ± 2.8%). Considering that those reefs suffered from extensive bleaching that killed an estimated 90 percent of the country's corals in 1998, any further damage to the coral reefs must be taken seriously.

16B Coral-microbe interactions & disease
Thursday 12 July, 1030, MR3

Are coral diseases contagious: testing a 30-year -old assumption?

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Coral reef ecologists have assumed that coral diseases are contagious, yet researchers have not tested this assumption. We used spatial epidemiology, or disease mapping, to test the assumption that coral colonies with disease will cluster. A hierarchical sampling design was applied over multiple spatial scales (among sites: 100 -101 km and among colonies: 10(-2) -10(-1) km) within 3 locations: St. John and St. Croix, US Virgin Islands and La Parguera, Puerto Rico, over time (2009 and 2010). Point-pattern analysis was used to examine the dynamics of the spatial distribution of 3 diseases, (i) Caribbean yellow band on *Montastraea annularis* spp., (ii) dark spot on *Siderastrea siderea* and (iii) white plague on *S. siderea.* Our results showed that no disease consistently clustered, suggesting that these diseases do not generally follow a contagious-disease model. The spatial epidemiology highlighted in this study suggests that at least 3

diseases within the Caribbean, are not consistently contagious. Indeed, transmission rates among sites and colonies may be negligible when attempting to model coral diseases over space and through time.

16B Coral-microbe interactions & disease
Thursday 12 July, 1230, MR3

Metagenomic characterization of microbial communities associated with White Band Disease type I

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White band disease (WBD) type I is an infectious disease that has contributed to the unprecedented decline of 2 endangered Caribbean coral species, *Acropora cervicornis* and *A. palmata*. Recent studies point toward a bacterial pathogen, although its identity remains elusive. In addition, the disruption of associations among organisms that comprise the coral holobiont may also lead to disease, suggesting that community-level changes of the microbial consortium, rather than a single pathogen, may cause WBD. Here, we present a metagenomic approach to assess the composition of the microbial community living on healthy and diseased coral tissues of *A. cervicornis* and *A. palmata*. Specimens were collected in spring and summer over a 2 year period to assess community change across seasons and over time. Amplicon libraries of a 374 bp fragment of the ribosomal 16S were sequenced on a Roche 454 genome sequencer. Operational taxonomic units defined at 99% similarity were classified by database comparisons with BLAST and the Ribosomal Database Project (RDP). Differences in microbial community structure in healthy and diseased corals were explored using multivariate statistics, while patterns in microbial diversity were described by alpha and beta diversity calculators. Seasonal and annual variation in community composition suggest that microbial consortia are dynamic, and that data spanning multiple years are essential for distinguishing natural variability and disease-related changes. Despite seasonal and year-to-year variation, important differences distinguish healthy and WBD-infected tissue.

16B Coral-microbe interactions & disease
Thursday 12 July, 1145, MR3

Identification of human sourced acroporidserratiosis and examination of pathogen persistence

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During a 2003 acroporid serratiosis (APS) outbreak, a unique strain of the pathogen, *Serratia marcescens* strain PDR60, was identified from diseased *Acropora palmata*, human wastewater, non-host corals, and *Coralliophila abbreviata*. In order to examine humans as a source and other marine invertebrates as vectors and/or reservoirs of the APS pathogen, challenge experiments were conducted to determine infectivity of PDR60 from reef and wastewater sources. PDR60 from wastewater and diseased *A. palmata* caused disease signs in as little as 4 days, demonstrating that wastewater is a definitive source of APS and identifying human strain PDR60 as a coral pathogen. *A. palmata* inoculated with PDR60 from snails showed limited virulence, while elkhorn coral inoculated with PDR60 from non-host corals and with strain PDL100 showed a delayed pathogenic effect. Our results show that distinct strains of *S. marcescens* are capable of causing APS and that these strains show varying levels of virulence with time to disease lesions ranging 4-23 days. In order to define differences between strains and among isolates of the same strain, we examined their persistence in seawater microcosms. *S. marcescens* vary widely in their survival in seawater with strain PDL100 surviving for 12 h or less and strain PDR60 persisting for up to 27 days. Fitness in seawater of different *S. marcescens* may shed light on the mode of APS transmission; seawater tolerant strains may be more likely to become persistent or resident on the reef, whereas less halo-tolerant strains may be responsible for discrete outbreaks over short time periods.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1500, MR3

A detailed case study of coral white syndromes

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In the past decade, a virulent group of coral diseases known as white syndromes (WS) have impacted reefs throughout Indian and Pacific Oceans. Despite detailed descriptions of a number of these outbreaks, a great deal of

confusion remains regarding the factors influencing WS lesion initiation, disease progression rate, and the ultimate fate of infected colonies (i.e. cessation of disease progression or colony-wide mortality). The research presented here provides a detailed case study of WS that combines long-term, field-based disease monitoring with multifaceted, laboratory-based characterization of diseased corals. Spatial variability, host density dependence, and seasonality of WS infection were assessed through seasonal (spring, summer, fall, and winter) coral disease surveys on 3 outer shelf reefs on Australia's northern Great Barrier Reef. Infected colonies were tagged and photographed to assess disease progression rates and samples were collected for: histology, ApopTag *in situ* apoptosis detection, fluorescence *in situ* hybridization (FISH) with general bacterial and vibrio-specific probes, and high throughput sequencing-based bacterial community profiling. Additionally, a highly sensitive, quantitative PCR-based assay was applied to coral and water samples to determine concentrations of *Vibrio coralliilyticus*, the presumed causative agent of several white syndrome outbreaks in the Indo-Pacific. This research delivers critical insights into the dynamics of this important group of coral diseases by combining long-term disease monitoring with detailed physiological and microbiological assessment of diseased corals. It provides a definitive case description of WS, including information on the role of environmental, host, and microbial factors in WS pathogenesis.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1715, MR3

Diseases affecting crustose coralline algae in Curacao

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Although several studies have been published on the distribution and abundance of coral diseases, few consider diseases affecting crustose coralline algae (CCA), particularly at the species level. Using a series of species-specific surveys along the coast of Curacao, Netherlands Antilles, we quantified the distribution and prevalence of diseases affecting CCA. We found that diseases did not affect species equally but varied considerably in time and space. We report two syndromes: the Coralline White Band Syndrome (CWBS) and the Coralline White Patch Syndrome (CWPS). Both syndromes were more abundant on reef flats than forereefs. Disease prevalence was greatest during warm periods. *Neogoniolithon mamillare*, one of the 2 dominant species on Curacao, was the most affected by diseases but the species was not present at all sites. *Paragoniolithon solubile*, the second most abundant species, was present at all sites and showed no difference among sites in disease prevalence. *Hydrolithon boergenesii* was the least affected by diseases, possibly because of its predominance in deeper habitats. Since the diseases affected dominant CCA species, they have the potential to cause major loss in CCA cover coupled with shifts in species composition, particularly in shallow waters. Coralline abundance monitored at nearby Bonaire has declined since 1999. Further research is needed to quantify the impact of these diseases on CCA population dynamics. As CCA play a key role in reef cementation and coral recruitment, our study suggests that the emergence of diseases affecting these algae may pose a real threat to coral reef ecosystems.

16B Coral-microbe interactions & disease
Thursday 12 July, 1215, MR3

Links between deteriorating coral health and sewage pollution of Guam reef flats

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Understanding links between water quality and coral health has become a global focus as reefs continue to decline. We examined the relationship between sewage-derived nitrogen (N) and coral disease on 7 reef flats along western Guam. We monitored coral disease prevalence and severity in conjunction with stable delta 15N isotope analyses of 2 species of marine algae and one soft coral collected bimonthly at each site, as an indicator for N pollution. Primary sources of N inputs at our sites included 2 sewage outfalls and a septic tank, where N leached into river systems and groundwater. Sewage pollution was evident at all 2 reefs, including our northern 'pristine' site. Mean total disease prevalence ranged from 1.4% to 24.5%, and delta ^{15}N ratios ranged from 2.7-5.6‰. There was congruence between N enrichment and prevalence for all but the 2 southern sites, which had the highest disease prevalence but the lowest delta ^{15}N values. The lack of congruence at some sites is likely due to variation in current patterns. For instance, at Piti Marine Reserve, disease prevalence decreased north-to-south,

coinciding with current patterns within this reserve. A spatially-explicit study is underway to assess the relative contributions of point- vs. non-point sources of N and the overall magnitude of N pollution on Guam.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1445, MR3

Dynamics of a black band disease outbreak in Palau

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Coral diseases have significantly increased in recent years and are considered one of the major threats to coral reefs worldwide. Very little is known about the dynamics of coral diseases in the Pacific Region. This research assessed the dynamics of a black band disease (BBD) outbreak in Nikko Bay, Palau. The objectives of this study were to quantify the rate of BBD progression across colonies of *Pachyseris speciosa*, determine prevalence of BBD in the Nikko Bay population, determine incidence and rate of spread of BBD throughout Nikko Bay population, identify potential environmental drivers of BBD in this region, and to evaluate the role of MPAs in managing coral disease outbreaks. Monitoring of colonies of *Pachyseris speciosa* over 5 months in Nikko Bay indicates that the mean rate of linear progression of BBD is almost double during warmer months (2.18±0.27 mm/day) compared to cooler months (1.19±0.15 mm/day). This study showed that incidence of BBD was low, but increased threefold, from 0.06% to 0.19% of colonies infected by BBD per day between March and May. The prevalence of BBD gradually increased from 14% of *Pachyseris* colonies infected with BBD in January to 19% in May. There was an increase in the rate of partial mortality on *Pachyseris* colonies due to BBD between January and May. These results suggest that the spread of BBD in Nikko Bay may be influenced by environmental parameters such as sea surface temperatures. The role of MPAs in managing coral disease outbreaks should be explored further.

16B Coral-microbe interactions & disease
Thursday 12 July, 1255, MR3

Effects of viruses on *Acropora millepora* eggs and larvae

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Recently it has been established that viruses are associated with coral reefs and can possibly cause coral health deterioration. Studies also show that shifts in sea water-associated viral abundances occur after the massive coral spawning events on the Great Barrier Reef. Therefore, it is possible that these viral shifts are occurring because viruses infecting coral eggs and larvae are released into the water column. To determine if viruses infect corals during fertilization, development, or settlement, we isolated viral-like particles (VLPs) from seawater before, during, and after coral spawning. VLPs were then concentrated with a TFF (tangential flow filtration). Eggs and embryo cohorts were exposed to concentrated VLPs and monitored for mortality and abnormal development or settlement. Egg bundles were collected from 6 coral colonies of *Acropora millepora* at Orpheus Island, on the Great Barrier Reef. Four crosses were generated and concentrated VLPs were added to each cross 1) prior to fertilization, 2) at the 2-cell stage, and 3) prior to settlement. Also, using virus specific primers, changes in viral consortia were evaluated in the concentrates and in exposed sample cohorts. Our data indicate that viral concentrates have a negative effect on coral fertilization, development, and settlement. Viral infections can thereby be detrimental to the development of corals and can possibly reduce overall coral reef fitness.

16B Coral-microbe interactions & disease
P172

Investigation of the disease, *Montipora* Linear Growth Anomaly, affecting *Montipora* capitata in Kane`ohe Bay, Hawaii

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Reef building corals are of economical, ecological, and cultural importance, and coral disease is a rising problem for coral reefs worldwide. Kane`ohe Bay, O`ahu, is a prime example of an ecosystem that has been impacted by numerous coral diseases such as *Montipora* White Syndrome, *Porites* Growth Anomalies, and *Porites* Tissue Loss Syndrome. In 2008, a new disease was observed on the common reef coral, *Montipora capitata*. This disease we term, *Montipora* Linear Growth Anomaly (MLGA) manifests as ridge-like structures on the surface of colonies. Thirteen sites around Coconut Island within Kane`ohe Bay were surveyed and MLGA was found at 2 of the sites (frequency of occurrence=15%). These 2 sites were re-surveyed through time and the average disease prevalence was found to be 37.7% (SE±2.4%) and 53.1% (SE±3.3%).

Both sites where MLGA was found were enclosed lagoons with high sedimentation and limited water motion. Twenty-two MLGA colonies and 10 healthy colonies were tagged and observed over time (2009-2011). Partial colony mortality occurred in 16% of the tagged MLGA colonies with no mortality occurring in the healthy controls. Morphometrics were examined between MLGA and healthy fragments and found MLGA-affected coral had reduced verrucae (MLGA 1.44 ± 1.70 verrucae/cm^2; healthy 10.25± 2.34 verrucae/cm^2) and polyp densities (MLGA 15.62± 2.48 polyps/cm^2; healthy 18.65± 2.54 polyps/cm^2). Additional work is underway to further elucidate this disease.

16B Coral-microbe interactions & disease
P170

Microbial drivers in the development of black band disease

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Black band disease (BBD) is a polymicrobial infection affecting corals worldwide and causing localised mass mortality, particularly in warm temperatures. The microbial mechanisms contributing to the development of BBD are poorly understood. Characteristic cyanobacterium-infected lesions, termed cyanobacterial patches (CP), were found to precede the onset of BBD in ~20% of cases on a GBR reef. Slower progression rates of CP than of BBD indicate that the virulence of lesions intensifies as BBD develops from CP. Concurrently, microbial communities within lesions exhibit transitional changes, including a shift in the dominant cyanobacteria and occurrence of sulphate reducing bacteria (SRB). Bacterial and archaeal communities within CP and BBD and associated microenvironmental parameters were investigated to understand the drivers of microbial dynamics in the development of BBD. Chemical profiling of the lesions using microsensors illustrated that CP mats are oxygenic and devoid of sulfide in light, whereas BBD mats are anoxic and highly sulfidic in darkness, confirming these microenvironmental factors are keys in the development of BBD. Quantitative PCR targeting the dissimilatory sulphite reductase gene (dsrA) shows that the abundance of dsrA gene copies increased in the transition from CP to BBD. Clone libraries of archaeal 16S ribosomal RNA genes also showed a shift from aerobic populations in CP to novel archaea related to strictly anaerobic methanogens, syntrophic to SRB, in BBD. Comparative metagenomic approaches to CP and BBD further identified other key players in BBD pathogenicity. These results highlight the importance of sulfur cycle-related microbial communities in the pathogenesis of BBD.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1200, MR3

Viruses as Putative White Plague Type II pathogens

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White Plague Type II (WPII) has been a threat to Caribbean reefs because it affects over 45% of the local reef building coral species. Previous studies on White Plague Type II (WP II) have focused on identifying potential bacterial pathogen, but these studies have been inconclusive. Therefore, an alternative hypothesis is that viruses are the causative pathogens in some forms of WP II. Using a combination of transmission electron microscopy (TEM) and next generation sequencing (454 pyrosequencing), we compared the viral composition of *Montastraea annularis* tissue from 2 areas of the diseased coral: the bleached top of the colony (N=7) and the base of the colony, where the disease was progressing (N=7). Tissue from bleached corals (N=6) and unbleached, healthy corals (N=2) were taken as controls. Sequences from diseased tissue had fewer similarities to viruses in NCBI than healthy and bleached tissue sequences. Diseased tissues also have undescribed viral types that have similarities to the viral family, Flaviviridae. These viral types were exclusive to the diseased samples; none were found in any healthy or bleached tissues, suggesting their role as pathogens. In addition, bleached tissue types had a higher abundance of Phycodnaviridae and other plant infecting viruses then diseased and healthy tissues, suggesting this viral family may play a role in bleaching. This is the first study to find a positive correlation of certain viruses with WP II diseased and bleaching corals.

16B Coral-microbe interactions & disease
Thursday 12 July, 1000, MR3

Health of mushroom corals in Pagerungan, Sepanjang, and Kangean Island, Indonesia

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Coral disease is one of the key factors causing the decline in reef condition. Therefore, it is important to collect data on coral diseases to prevent widespread damage from coral diseases. There are several observational sites at Pagerungan, Sepanjang Island, and Kangean Island, Madura, Indonesia. Disease surveys along belt transects were conducted at a depth of 5 meters. All coral genera found within the belt transect (50x5 m) were recorded and any diseases identified found on coral. The coral diseases that dominated all 3 stations were Non Focal Bleaching (stripes, patches and spots) and Yellow Band Disease (YBD). YBD is commonly found in fungiids at Pagerungan, Sepanjang Island, and Kangean Island. At all survey sites at Pagerungan, Sepanjang Island, and Kangean Island, the number of coral reefs affected by diseases exceeded healthy coral abundance.

16B Coral-microbe interactions & disease
Thursday 12 July, 1250, MR3

Ciliate and bacterial communities associated with White Syndrome and Brown Band Disease in reef building corals

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Coral pathogens are routinely detected in healthy corals. To understand disease causation, we must be able to distinguish between pathogens that are capable of causing damage and which may proliferate under stressful conditions, and those that are directly involved in a specific pathogenesis and heterotrophs that colonise dead and decaying tissues following disease. As a first step to understanding the common Indo-Pacific coral diseases White Syndrome (WS) and Brown Band Disease (BrB), we applied culture-independent molecular techniques to describe both ciliate (18S rRNA gene) and bacterial (16S rRNA gene) communities. The community profiles were highly similar between the 2 diseases. Four bacterial and 9 ciliate ribotypes were observed in both diseases, but absent in non-diseased specimens. Only one of the bacteria, *Arcobacter* sp. (JF831360), increased substantially in relative 16S rRNA gene abundance and was consistently represented in all disease lesion samples. Four of the 11 ciliate morphotypes detected contained coral algal symbionts, indicative of the ingestion of coral tissues. In both WS and BrB, there were 2 ciliate morphotypes consistently represented in all disease lesion samples. Morph1 (JN626268) was observed to burrow into and underneath the coral tissues at the lesion boundary. Morph2 (JN626269), previously identified in BrB, appears to play a secondary, less invasive role in pathogenesis, but has a higher population density in BrB, giving rise to the visible brown band. The strong similarity in bacterial and ciliate community composition of these diseases suggests that they are actually the same syndrome, so we recommend that they are synonymised.

16B Coral-microbe interactions & disease
Thursday 12 July, 0945, MR3

Primary and secondary bacterial pathogens involved with *Montipora* White Syndrome

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The coral *Montipora capitata*, a major component of the reefs in Kaneohe Bay, Oahu, Hawaii, is afflicted by the transmissible, tissue-loss disease *Montipora* white syndrome (MWS). MWS has been observed in the field and laboratory to have 2 disease presentations; acute and subacute. The acute phase produces a rapid, short-term loss of tissue, while the subacute phase produces slower but chronic tissue loss. Two different bacterial strains able to induce MWS under controlled laboratory conditions were isolated from diseased *M. capitata* fragments. Challenge runs were conducted, during which healthy fragments of *M. capitata* were exposed to axenic cultures of each pathogen, with *Alteromonas* sp. (isolate OCN004) as a bacterial control. The isolate OCN002, of the genus *Vibrio*, was shown to be a primary pathogen able to induce either form of MWS in healthy *M capitata*. OCN002 had an infection rate of 53% (n= 13 mean incubation period=28 days) and was re-isolated from disease-induced laboratory specimens. The isolate OCN003, of the genus *Pseudoalteromonas*, initiated only the acute phase of MWS in fragments. OCN003 had an infection rate of 30% (n= 13, mean incubation period= 22 days) when tested as a primary pathogen, but a 60% infection rate (n= 20 , mean incubation period= 4 days) when tested as a secondary pathogen and was also re-isolated from laboratory-infected fragments. Control fragments showed no signs of tissue loss. This study identifies a *Vibrio* sp. as a potential primary pathogen, while suggesting a *Pseudoalteromonas* sp. as a primarily opportunistic secondary pathogen.

16B Coral-microbe interactions & disease
Thursday 12 July, 1015, MR3

Invading pathogens following physical damage elicit immune response in corals

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Reports of rising coral disease prevalence world-wide indicate that coral diseases have become an important factor contributing to the degradation of coral reefs. Increases in seawater temperature have been shown to affect coral-associated bacterial communities, causing a shift towards pathogenic species. However, factors influencing the onset of coral diseases are still unknown. Physical damage to coral colonies, for example, as caused by predation, grazing, cyclones and anthropogenic activities (e.g. diving, fishing), may create lesions that facilitate infection by pathogenic bacteria. To investigate the role of physical injury in the onset of coral disease, we investigated the response of corals to tissue damage using immunological and microbiological assays. Tissue damage was inflicted on colonies of *Acropora aspera* in its natural habitat and injured colonies were followed over time. Corals upregulated the expression of fluorescent proteins, indicating a stress and recovery response. Gene expression analysis of immune system-related genes showed 2 immune responses: an early response, likely to be linked to the initial injury, followed by a second strong and prolonged response, potentially as a reaction to a pathogenic infection. To confirm our hypothesis, changes in the composition of coral-associated bacterial communities and bacterial colonisation patterns are currently being investigated. In conclusion, we have shown that corals respond quickly to physical damage by eliciting a response that enhances their potential to recover and resist potentially invading pathogenic micro-organisms. However, injury may provide a point-of-entry for pathogens and therefore may play a significant role in the onset of coral disease.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1515, MR3

Coral disease dynamics in the US Pacific Territories and States

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The spread of coral diseases continues to pose escalating threats to coral reef health, biodiversity, and community resiliency. Since 2006, the Coral Reef Ecosystem Division of the NOAA Pacific Islands Fisheries Science Center has conducted biennial monitoring of coral disease distribution and abundance throughout the U.S. Pacific Territories and affiliated states. This study examines the spatial, demographic, and environmental correlates of disease in the region based on Rapid Ecological Assessment surveys conducted at nearly 400 discrete sites, at 42 different U.S. Pacific islands and atolls, within 5 major geographic regions: main Hawaiian Islands (MHI), Northwestern Hawaiian Islands (NWHI), American Samoa, the Pacific Remote Island Areas (PRIA), and Guam and the Commonwealth of the Northern Mariana Islands (CNMI). After compromised health conditions, the most prevalent disease states Pacific-wide were white syndrome/tissue loss, skeletal growth anomalies, and endolithic hymermycosis. Mean disease prevalence varied significantly Pacific-wide among islands and regions, driven in part by the differential degree in which certain coral taxa were affected by disease. Disease prevalence correlated with regional and local community structural and demographic parameters, as well as environmental conditions, such as temperature. Although disease prevalence is generally low in the 5 regions, values up to 10% occur around Guam. Results also suggested the presence of hotspots in unpopulated locales and absence of any ongoing major outbreak events. The information presented herein provides much-needed local and regional insights to support resource managers and policymakers in their efforts to implement effective strategies which enhance resilience of coral reefs.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1645, MR3

Empirical metagenomic investigations on the roles of coral viruses and microbes

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The relationship between corals and their microbes and viruses is complex and dynamic. While microbes are hypothesized to play a wide variety of context-dependent roles in the ecology of coral reefs, how both biotic and abiotic alterations of the environment affect the coral microbiome is still unknown. Even more, the types and effects of viruses on coral health are only beginning to be investigated, with only 22 manuscripts on the topic published to date. We use empirical metagenomics, microscopy, and molecular and culturing techniques to investigate the taxonomic and functional diversity of microbes and viruses associated with a variety of corals. Using data from our

long-term field manipulation experiments, we find that inorganic nutrient input (a bottom up stressor) and over-exploitation of fish stocks (a top town stressor) combine to significantly disrupt the bacterial communities associated with corals. The mechanism of this alteration is likely the increasing interactions of corals and macro-algae, and we will present data on coral-algal competition studies that support this hypothesis. Our work also demonstrates that there are 3 major families of viruses in stony corals: Phycodna-like, Herpes-like, and Irido-like viruses. How these viruses affect coral health is currently unknown, but we will present the first evidence that temperature and UV stress induce production of a novel Phycodnavirus in corals which we hypothesize to infect the algal partners of coral, *Symbiodinium*. Lastly, we will present data on the etiological agents of two coral diseases, *Porites lobata* growth anomalies and *Montastraea annularis* White Plague II.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1730, MR3

Probing stony coral rapid tissue necrosis with optical oxygen sensors

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Rapid tissue necrosis (RTN) has been one of the typical symptoms of infectious disease in stony corals. Due to the acute and cryptic nature of the necrosis, it is often difficult to detect the onset of the coral disease early on. In order to overcome such difficulties and to contribute to disease prevention, we aimed to develop a disease monitoring system by employing a fluorescent-based oxygen sensor (optode), and to gain insight into the pathology of RTN. Branches of acroporids with apparent necrotic lesions were collected from Okinawa Churaumi Aquarium, Japan. Each specimen was kept in seawater and examined for photosynthetic potential with an imaging PAM (MAXI-version, Walz). An optode (NeoFox, Ocean Optics) was then positioned close to the specimen. Under a repeated cycle of light/dark conditions, regions with active photosynthesis produced more dissolved oxygen (DO) under light than dark, and were net autotrophic. In contrast, lesions with little photosynthetic activity often were net heterotrophic, despite unexpectedly higher DO concentrations under light. Microscopic observations revealed that bleached areas were in most cases heavily colonized by ciliated protozoa, presumably feeding on coral tissue and zooxanthellae. We believe that heterotrophic activity of the microbes contribute substantially to the DO consumption. These results demonstrate that an optode allowes one to monitor fine-scale dynamics of DO levels around coral tissues in non-invasive manner, and provide a simple and effective way to probe development of RTN on stony coral.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1430, MR3

***Acropora cervicornis* symbionts and disease investigated by next generation sequencing**

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Acroporids were once the primary reef building corals throughout the Caribbean, but have experienced significant population decline since the 1970s. Unlike much of the Caribbean, *Acropora cervicornis* is still abundant on the nearshore reef habitats offshore southeast Florida as patches and scattered individual colonies. Monitoring of this population, especially the densely populated patches, has shown disease, specifically a condition known as rapid tissue loss (RTL), to be a significant source of mortality. This project examines the *A. cervicornis* bacterial communities associated with tissue and mucus of 3 health conditions: completely healthy, apparently healthy branches on diseased colonies, and diseased margin. From 2 high-density sites a total of 54 tissue and mucus samples were collected from colonies representing each of the conditions. Small tissue fragments and mucus were collected for microbial DNA isolation. PCR amplification of 16S rRNA variable regions (V1-V3) from the total metagenomic DNA was carried out using universal bacterial primers. Following PCR amplification, Roche fusion primers and multiplex sequence identifiers (MIDS) were attached to each sample for '454' next generation pyrosequencing. Resulting sequences were analyzed for identifiable bacterial operational taxonomic units (OTUs) through annotation with taxonomic information using standard bioinformatics approaches (QIIME, RDP) against 16S rRNA databases (GenBank and Silva). Statistical detection was performed on the resulting 16S rRNA sequences generated for differentially abundant taxonomic groups across the 3 sample types. The resulting data provide a baseline bacterial community structure characterization associated with each condition as well as the identification of potential etiological agents.

16B Coral-microbe interactions & disease
Thursday 12 July, 1245, MR3

Coral disease in Oahu's marine life conservation districts

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Coral disease has been identified as one of the major causes for coral mortality, making coral disease and health a top concern for the conservation of coral reefs globally. Despite awareness of the threat that disease poses to corals, there has been limited research on the prevalence of disease within Oahu's Marine Life Conservation Districts (MLCDs). Past studies have suggested that protection status not only influences the abundance of herbivorous fish, macroalga levels, and coral cover, but also the prevalence of coral disease. We investigated coral reef ecosystem health inside Oahu's 3 MLCDs compared to 3 adjacent unprotected reefs. Field surveys were used to quantify coral disease prevalence, coral cover, fish abundance and diversity, and coral community size structure at each of the sites. Environmental variables including temperature, sedimentation, inorganic-organic carbon fraction of sediments, rugosity, and water motion were also measured. Biological and environmental parameters as well as protection status were used in a statistical model to determine what variables were the best predictors for coral disease prevalences. This study is particularly interested in the role that protective status plays in coral disease levels and overall coral ecosystem health.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1530, MR3

Predatory *Bacteriovorax* give corals a fighting chance against pathogens

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It has been suggested that some bacteria provide benefits to their associated corals. Here, we test that hypothesis while highlighting the potential role of a newly discovered member of the coral microbiome, *Bacteriovorax* spp. *Bacteriovorax* are highly motile gram negative bacteria that prey exclusively on other bacteria including many known pathogens. Due to their predatory lifestyle and broad prey range, these newly described members of the coral microbiome may play roles in structuring the microbial community. First, to confirm the presence of *Bacteriovorax* on corals, we used 16S rDNA primers on DNA extracted from coral mucus of *Siderastrea siderea* and *Porites astreoides*. We then isolated *Bacteriovorax* strains from the coral species: *S. siderea, P. astreoides*, and *Montastraea cavernosa* (6,7 and 1 isolate respectively). Phylogenetic analysis confirmed the identity of these predatory bacteria. To illuminate the role of *Bacteriovorax* on the coral microbiome, we inoculated *M. cavernosa* corals with 109 *Vibrio harveyi* (a suspect coral pathogen) or 109 *Vibrio coralliilyticus* (a known pathogen) in the presence and absence of 106 *Bacteriovorax* strain L. Sterile media was used as a negative control. Our results suggested *Bacteriovorax* may prevent or reduce infection of these *Vibrios* on corals. *Bacteriovorax*, a previously undetected yet ecologically relevant member of the coral microbiome, can be readily isolated and used in controlled laboratory settings. Furthermore, we have establish a three part model system using known pathogens and *Bacteriovorax* for bacteria-coral interactions that will allow us to better test the complex roles of microbes and coral reef health.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1400, MR3

Long-term patterns in coral disease on the Great Barrier Reef

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Coral health is a cornerstone of reef resilience; however, fundamental knowledge of baseline levels of coral disease characteristic of a resilient coral reef ecosystem is lacking. Here, we present patterns in the prevalence of coral disease over 8 years (2004-2011) on 3 cross-shelf transects, which include replicate inshore, midshelf and offshore reefs, in the northern, central and southern sections of the Great Barrier Marine Park. We also relate patterns in disease prevalence with patterns in thermal stress, as determined using the Reef-Temp model. Overall, disease prevalence was low, typically less than 4% over the 8 years. In general, disease prevalence declined throughout the 8 years of the study, which followed a peak in thermal stress in 2002-03. Patterns of higher disease prevalence in summer compared to winter further highlight the importance of thermal stress as a major driver of disease occurrence. Long-term monitoring confirms the higher susceptibility of acroporids and pocilloporids compared to other coral families. Our baseline data have contributed to the development of a threshold matrix for outbreaks of virulent, temperature-related diseases, like white syndromes and

black band disease, which is based on both the spatial extent and abundance of coral disease. The matrix forms an important component of the Great Barrier Reef Marine Park Authority's Disease Response Plan and can be readily adapted to other reef locations for managing coral health.

16B Coral-microbe interactions & disease
Wednesday 11 July, 1630, MR3

Mechanisms involved in chemotaxis and motility during infection onset

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Vibrio coralliilyticus is a known coral pathogen of ecological importance for the health of coral reefs worldwide. Fundamental to understanding the pathogenesis and virulence of this microorganism is infection initiation by motility and chemotaxis, which controls the potency and speed of infection. Here, the focus is specifically on the first two steps of infection, the bacterial flagellum and virulence-associated type III injectisome. These nanomachines control movement (step 1 in infection), whilst the injectisome translocates effector proteins across the host membrane into the coral cytoplasm. To date, little is known about these initial infection steps. Using a three-pronged approach that incorporates bioinformatics, gene expression analysis and microscopy, this study examined the motility and virulence mechanisms of this pathogenic microorganism. Searching strategies were analysed for *Vibrio coralliilyticus*, using microscopy and video tracking. Variation in frequency, type of search patterns and speed was found between areas of depleted oxygen compared to the high oxygen content present at the cover slip edge providing evidence that these bacteria alter their searching strategies based on spatial and chemical gradients. In addition, we showed that different search patterns in areas of high oxygen content were linked with changes in speed. Furthermore, influential flagellar motor and type III injectisome genes were analysed across differing temperature and chemical gradients to simulate environmental seawater changes. Obtaining a greater understanding of the steps involved in infection onset in *V. coralliilyticus* will aid management strategies for the preservation of corals worldwide and how this microorganism could behave in a warming climate.

16B Coral-microbe interactions & disease
P169

Outbreak of diatoms and cyanobacteria on corals

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Japanese corals as well as other countries are in crisis. In addition to bleaching and crown-of-thorns starfish outbreakes, diseases and syndromes on corals in Japan are increasing and causing severe problems for reef health. The present reseach highlightes some known and new diseases or overgrowth by small organisms (cyanobacteria or diatoms) leading coral death.

16B Coral-microbe interactions & disease
P171

16C Immune defences of coral reef organisms

The immune response of the coral *Acropora millepora* under CO_2 stress

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Coral diseases pose a major and increasing threat to coral reefs globally, and one major difficulty in addressing this problem is that the coral immune system is poorly understood. Anecdotally, diseases have a greater impact on corals that are already under stress, and while this is highly probable, until very recently there has been little empirical support for this hypothesis. Recent evidence indicates that for the coral *Pocillopora damicornis*, higher seawater temperatures result in coral tissue lysis as a result of *Vibrio coralliilyticus* infection, which is consistent with the idea of additive or synergistic effects of stressors. Our laboratory has focused on the staghorn coral *Acropora millepora* as a model for understanding many aspects of coral biology. To better understand the effects of pathogens on corals, we have investigated the response of *A. millepora* to defined immunogens using mRNA sequencing (Illumina RNA seq) technology. As well as contributing to an understanding of coral immunity, our research has uncovered some surprising cases of apparent conservation between the coral and vertebrate immune systems. Although in terrestrial animals, hypercapnia impairs the immune response, nothing is known about the influence of elevated CO_2 on immunity in the marine environment. We are presently investigating the effects of CO_2 stress on the immune

response of *Acropora* to better understand possible effects of disease on corals that are already under stress. Results of these analyses will be presented, and their broader implications discussed.

16C Immune defenses of coral reef organisms
Friday 13 July, 1130, MR3

Healing and early regeneration in Anthozoan Cnidarians

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Coral reef resilience is defined by its ability to resist, heal, and regenerate after localized stress events. In nature, coral polyps regularly suffer injuries from corallivorous fish, invertebrates, wave action and storm surge. The ability to recover from these routine injuries can be compromised by increasingly severe anthropogenic threats that include ocean warming and acidification, pollution, and destructive fishing practices, as well the spread of coral pathogens. In order to understand how wound healing is impacted by environmental stress in corals and other cnidarians, we need to understand the molecular basis of wound healing under non-stressful conditions. In this study, we used deep mRNA sequencing to develop a transcriptional profile of wound healing in cauliflower coral *Pocillopora damicornis* and the starlet sea anemone *Nematostella vectensis*. Animals were wounded in a systematic manner, and mRNA was isolated at regular intervals following wounding. Non-normalized libraries were sequenced using the Illumina platform, and the resulting data were subjected to a battery of bioinformatics analyses to assemble and annotate the resulting transcripts and to detect differential gene expression.

16C Immune defenses of coral reef organisms
Friday 13 July, 1430, MR3

The coral surface mucus layer: the first line of defence?

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The coral surface mucus layer (SML) is widely recognised as an important barrier to pathogen invasion, although it is also known to serve a number of other important roles in the physiology and ecology of the coral. In fact, the structure, function, and composition of surface mucosa has been highly conserved throughout animal evolution since it first appeared in the Cnidaria. We describe here a bilayer structure to the SML. An inner 4-30 µm thick gel layer appears to represent a barrier layer, whereas a fluid, 0.3-0.6 mm outer layer serves a particle transport function. Perceptions of the SML tend to be represented by static models, and numerous studies show a unique microbial community composition in the SML, which indicates that the associated microbial communities must develop over hours or days rather than minutes. Paradoxically, we show here that the outer SML is a highly dynamic layer, with rapid (minutes rather than hours) turnover. SML movement was directed and co-ordinated across the coral colony to support one of two ecological processes: surface cleansing (shedding of the SML to the water column) or feeding (ingestion of the SML and trapped particles). All species studied undertook both surface cleansing and feeding at different times, however the timing and controls regulating the shift between the two processes are not known. The SML is clearly a complex, dynamic environment and further work in this area is critical to understanding the first stages of host-pathogen interactions.

16C Immune defenses of coral reef organisms
Friday 13 July, 1030, MR3

Host-microbe interactions in the cnidarian *Hydra*

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All metazoans are associated with a coevolved microbial community, which confers a variety of beneficial effects to the host. In recent years, it became evident that a disturbed host-microbe homeostasis is involved in the process of coral bleaching, threatening coral ecosystems worldwide. Control over the microbiota, therefore, might contribute to maximize the host´s fitness. By making use of transgenesis in the model cnidarian *Hydra*, we deciphered the role of different innate immune pathways in the establishment and maintenance of the host-microbe homeostasis. The innate immune system of *Hydra* includes a conserved Toll-like-receptor (TLR) -signaling cascade, a large variety of intracellular pattern recognition receptors called Nod-like receptors, and potent antimicrobial peptides. By interfering with the TLR-pathway via MyD88 loss-of-function experiments, followed by microarray-based gene expression screening and 454 sequencing of associated bacteria, we demonstrated that TLR-mediated sensing of commensal bacteria is essential for controlling

abundance, diversity, and composition of the associated microbiota. Furthermore, we show that the *Hydra* antimicrobial peptide (AMP) family arminin has expanded during evolution in different Hydra species and that trans-species overexpression of arminin results in a changed composition of colonizing bacteria across host species identity. AMPs, therefore, might play a key role in habitat-specific adaptations by facilitating the control of habitat-specific bacterial colonizers. These insights indicate a tight link between host tissue and the commensal microbiota, and promise to unveil ancient mechanisms derived from the *in vivo* context of a whole epithelial organism that controls tissue- and host-microbe homeostasis.

16C Immune defenses of coral reef organisms
Friday 13 July, 1245, MR3

Possible roles of the complement pathway in cnidarian-dinoflagellate symbiosis

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The molecular and cellular biology of the cnidarian-dinoflagellate (*Symbiodinium*) symbiosis is poorly understood, largely because of the difficulties of experimentation on corals. Thus, we are focusing on the small sea anemone, *Aiptasia*, as a more tractable model system. Most cnidarian larvae initially are aposymbiotic (dinoflagellate-free) and are then colonized by algae acquired from the environment. We hypothesize that host innate-immunity pathways are involved in symbiosis establishment and may be responsible for distinguishing among compatible *Symbiodinium* strains, incompatible *Symbiodinium* strains, and pathogens. We are focusing on the complement pathway, whose localization and activities in other organisms make it a likely candidate for involvement in symbiont recognition. We are using qPCR, *in situ* hybridization, and antibodies specific for the key complement protein C3 to monitor C3 transcript levels, protein levels, and localization in aposymbiotic *Aiptasia* (adults and larvae) upon exposure to various *Symbiodinium* strains and pathogens. Preliminary immunohistochemistry results show marked differences in C3 localization between aposymbiotic and symbiotic *Aiptasia*. We will also perform RNA-mediated knockdown of C3 and assess the resulting changes in the specificity and dynamics of symbiosis establishment. The upstream components of the complement pathway include sugar-binding lectins, which bind to microbial oligosaccharides (glycans). Removing such glycans from *Symbiodinium* has been reported to inhibit their uptake by cnidarian hosts. We plan to use lectin-blocking sugars and/or RNA-mediated knockdown to identify lectins that may be important in the establishment of symbiosis.

16C Immune defenses of coral reef organisms
Friday 13 July, 1145, MR3

Xenophagy: an important first line of defense in coral immunity

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The Scleractinia are evolutionarily basal organisms that are susceptible to diseases caused by intracellular pathogenic bacteria. They also host a variety of intracellular mutualistic symbionts (endosymbionts) ranging from bacteria to protists with numerous recognition pathways for the establishment and maintenance of these symbioses. The questions that arise then, is what cellular mechanisms allow them to protect themselves from intracellular pathogens on the one hand, and to maintain such symbioses on the other. To address this paradox, we compared cellular changes occurring in tissues of corals affected by intracellular pathogens with those affected by environmental stressors that resulted in symbiont uncoupling. We found similarities in the cellular parameters occurring during environmental stress response and pathogen infection processes. These responses include the sequestering of the foreign organisms in phagosomes. If the organism is recognized as foreign, it is then actively destroyed and digested using a highly regulated autophagous pathway (xenophagy). If no such recognition occurs or it is actively recognized as a symbiont it is sequestered in a phagosome and symbiosis occurs. Moreover, if this recognition process is disrupted, the symbiont is then also digested via the same xenophagic pathway. We found that the processes of pathogen and symbiont xenophagies share a number of markers including, changes in host cell ER morphologies, as well as changes in molecular markers. The results suggest a common immune mechanisms operating in the symbiosis-pathogenicity continuum, and that these mechanism are regulated by environmental conditions.

16C Immune defenses of coral reef organisms
Friday 13 July, 1200, MR3

Temperature effect on host-pathogen dynamics of Caribbean octocoral, *Gorgonia ventalina*

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The Caribbean sea fan, *Gorgonia ventalina* and its associated fungal pathogen, *Aspergillus sydowii* are good models for demonstrating the effects of temperature stress on host pathogen interactions. We hypothesize that temperature stress is contributing to overall disease prevalence of *G. ventalina* by compromising the host immune response and/or exacerbating pathogen virulence. Proteolytic enzymes, or proteases, are used by many pathogens to colonize and infect a host; conversely, many hosts utilize protease inhibitors to combat these pathenogenic enzymes. Using a fluorescent-labeled casein substrate, protease inhibitor activity was measured as an immune response of *G. ventalina* colonies naturally infected with *A. sydowii* and healthy colonies that underwent temperature stress. Activity against commercial serine proteases and *A. sydowii* derived proteases varied with infection, with healthy colonies having the highest anti-protease activity. Healthy colonies that were exposed to natural temperature stress during a bleaching event showed higher levels of anti-protease activity than those collected prior and after stress. In addition to host effects, temperature also caused an increase in protease activity in marine strains of *A. sydowii* cultures. These data illustrate the important role that abiotic factors, such as temperature stress, play in host-pathogen dynamics. The need for increased monitoring of host immunity and disease resistance for coral reef inhabitants is imperative to better mitigate and manage decline of these ecosystems due to climate change.

16C Immune defenses of coral reef organisms
Friday 13 July, 1215, MR3

Density-dependent prophylaxis in the crown-of-thorns starfish

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The density-dependent prophylaxis hypothesis predicts that individuals at high density will invest more resources into immune defence than individuals at lower densities as a counter-measure to density-dependent pathogen transmission rates. Evidence has been found for this hypothesis in Lepidoptera, but not in a non-arthropod taxon. To investigate this hypothesis in the crown-of-thorns seastar, *Acanthaster planci*, density treatments were set up over 21 days and pathogen infection was simulated with bacterial injection. Five immune responses: amoebocyte count, amoebocyte viability, lysosomal membrane integrity, respiratory burst and peroxidase activity were all upregulated at high density. These results demonstrate that immune investment shows phenotypic plasticity with population density in agreement with the density-dependent prophylaxis hypothesis. *Acanthaster planci* upregulate their immune response at high density to increase disease resistance in response to greater exposure to pathogens, an adaptation to their frequent population explosions.

16C Immune defenses of coral reef organisms
Friday 13 July, 1400, MR3

The immune response of *Pocillopora damicornis* confronted with *Vibrio coralliilyticus*

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Among disturbances affecting corals, coral diseases are increasing in frequency and severity, often in correlation with increase of seawater temperature. Despite a growing number of studies in this research field, knowledge on the innate immune response of corals facing pathogens remains fragmentary. In order to fill this gap, we investigated the physiological responses of a major reef-building coral, *Pocillopora damicornis*, when exposed to a specific pathogen (*Vibrio coralliilyticus*) under non-virulent (constant, low temperature) and virulent (increasing water temperature) conditions. The coral response to *V. coralliilyticus* was studied by comparing the transcriptomes of coral samples confronted to virulent or non-virulent *V.coralliilyticus* with non challenged samples. The comparative transcriptomic approach used was based on SSH or RNAseq/DEG Seq approaches. The results obtained allow the identification of several innate immune genes whose expression is up- or down-regulated following challenges. In order to strengthen and validate these results, we analyze several of these candidate genes identified using quantitative-PCR. This last approach allowed verification by an alternative approach--the transcription modulation triggered by virulent or non-virulent bacteria.

16C Immune defenses of coral reef organisms
Friday 13 July, 1115, MR3

Why do corals vary in susceptibility to disease?

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Corals vary in their susceptibility to disease at the species and population level. In many systems, the costs of evolving and implementing immune defenses drive resource trade-offs that result in widespread differences in disease resistance. Organisms that invest more into growth and reproduction have fewer resources for immune defenses, and vice versa. These differences in resource investment are responsible for the variation in disease susceptibility among species, while within species differences can be due to changes in physiological status that co-occur with changes in nutrition and temperature. Ecological immunology is an emerging field that considers natural variation in immune function as it relates to biotic and abiotic factors as well as broad scales ecological processes. Applying ecological immunology theory to corals has the potential to provide novel insight into the current broad and local-scale patterns of coral diseases. Here, we will integrate data from several experimental approaches and lines of research to show that corals do indeed differ in their baseline immunity and that these differences correlate to disease resistance. The patterns of immunity and disease from coral species in the Indo-pacific and Caribbean will be compared. The inducibility of immune mechanisms under natural and experimental temperature stress also differ among and within coral species. Baseline immunity and the ability for a coral immune system to respond to changing environmental stress are important determinants in how they will survive future changes and continued threats from disease.

16C Immune defenses of coral reef organisms
Friday 13 July, 1000, MR3

How to cause apoptosis in coral using human TNFa

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Anthozoa is a primitive class of Cnidaria and could be considered phylogenetically basal. Recent genomic comparisons of the Anthozoan *Nematostella vectenis* to *Homo sapiens* suggest high conservation of multiple gene families, including some involved in immunity. While the existence of these similar immunity genes has been demonstrated, the functional conservation of specific immune pathways between Anthozoans and *Homo sapiens* has yet to be investigated. The Tumor Necrosis Factor (TNF) system is a classical innate immune pathway that acts as a mediator of apoptosis and has been implicated in a wide spectrum of human diseases. We provide bioinformatic evidence, suggesting that corals express several similar proteins to members of the human TNF pathway, including the TNF receptor. To determine the functionality and evolutionary conservation of the TNF pathway we exposed *Acropora yongei* to human TNF, extracted proteins from whole tissue blastate, and performed 2D-Gel Electrophoresis followed by LC-MS/MS. Proteins that are characteristically downregulated during apoptosis were also downregulated in coral following TNF stimulation. Proteins that were upregulated suggest that TNF affects the physiology of the mitochondria and zooxanthallae. Imaging of individual coral cells using confocal microscopy demonstrated that TNF stimulation causes distinct morphological changes to cell structure indicative of apoptosis. Taken together, our data suggest that a functional TNF pathway is present in corals. The activation of this pathway with human TNF demonstrates remarkable conservation of the TNF-receptor binding domain and suggests that it has been maintained for over 550 million years.

16C Immune defenses of coral reef organisms
Friday 13 July, 1415, MR3

Gorgonian amoebocytes demonstrate differential staining and anti-lysozyme and anti-myeloperoxidase immunoreactivity

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The published Anthozoan immune genomes and ESTs include several vertebrate orthologs including toll-like receptors, the mannose binding lectin Millectin, and complement factor 3-like protein, among others. A melanin-synthesis pathway with phenoloxidase, peroxidase, and other antioxidants has been demonstrated within the functional Anthozoan immune system. The less well understood cellular immune response of many invertebrates, including Anthozoa, features the amoebocyte. It is postulated that pluripotent amoebocytes migrate to sites of infection and differentiate into granular amoebocytes. However, the *in situ* ontological biochemical composition of Anthozoan amoebocytes is largely unexplored. Here we present histological and immunohistochemical characterization of amoebocytes in healthy and

diseased samples from the sea fans *Gorgonia ventalina* and *G. flabellum*. We present tissue sections in which amoebocytes stain positively with Luna's, Giemsa, and Phosphotungstic acid haematoxylin (PTAH) special stains. Additionally, the cytoplasm of amoebocytes is strongly immunoreactive to anti-lysozyme and weakly immunoreactive to anti-myeloperoxidase. These amoebocyte special staining and immunohistochemical properties most closely resemble those for granules found in mammalian eosinophils and neutrophils, respectively. Attempts to utilize anti-human complement C3 antibody and anti-human CD23 antibodies (Millectin) with epitope specificity to conserved regions of published Anthozoan cDNA sequence were unsuccessful. Histological tools such as these will contribute to an improved understanding of immune system function in marine species, facilitating correlations between disease and environmental perturbation.

16C Immune defenses of coral reef organisms
Friday 13 July, 1230, MR3

Can sediment stress affect coral immunity?

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Diseases are increasingly affecting tropical corals worldwide, and are in part due to the influence of various environmental and anthropogenic factors including elevating sea surface temperatures and eutrophication. These factors have been shown to promote both coral disease prevalence and pathogen virulence. A recent study highlighted that land runoff and its associated effects such as increased particulate organic matter (POM) and lowered salinity, could also play a role in promoting coral disease. Sediments associated with terrestrial runoff and seabed sediment resuspension can affect scleractinian corals through several mechanisms including increases in POM, dissolved inorganic nutrients, sedimentation, and light reduction. Sediment deposits on corals have also been suggested to act as a reservoir of coral pathogens and can lead to coral tissue necrosis. Though sediments deposited on corals can generally be removed through mucus production and ciliary beating, such actions increase metabolic costs and could impact on the coral's immune potential and health, making it more susceptible to infections. In order to explore the effects of sediment deposition on coral health and immunity, 2 coral species were inoculated with marine sediments under controlled conditions. The effects of this inoculation were assayed through monitoring several coral health and immunity proxies including phenoloxidase activity, immune cell counts, and energy stores by measuring lipid content.

16C Immune defenses of coral reef organisms
Friday 13 July, 1445, MR3

Variability in antimicrobial chemical resistance to *Montipora* White Syndrome

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Corals possess a diversity of innate immune defenses against pathogenesis, and phenotypic or genotypic variability in these defenses is likely responsible for differential susceptibility to disease. Antimicrobial chemical defenses are one type of innate immunity expressed by corals, and variability in these innate chemical defenses has been demonstrated among species, populations, and individual colonies. We assessed variability in antibacterial chemical defenses in the Hawaiian coral *Montipora capitata*, which is susceptible to the tissue loss disease, *Montipora* White Syndrome (MWS). Antibacterial activity and chemical profiles from healthy and diseased tissues on colonies of *M. capitata* affected by MWS were compared with those from healthy neighboring colonies. Colonies of *M. capitata* exhibiting signs of MWS produced different levels of antibacterial chemical defenses than did healthy conspecific neighbors. Chemical fingerprints of *M. capitata* identified 2 compounds that differed in concentrations between healthy and diseased coral tissue. *Montipora capitata* occurs in 2 color morphs (red and orange) and orange colonies are significantly more susceptible to MWS than are red colonies from the same location. Extracts from the red color morph inhibited the growth of a greater diversity of bacteria than did the orange morph, and chemical profiles of the 2 color morphs also exhibited differences. Antibacterial chemical defenses may thus play a role in protecting *M. capitata* from disease. Differences in levels and types of antibacterial chemical defenses might enable particular colonies, populations or species to have an

ecological fitness advantage over others in resisting invasion by pathogens.

16C Immune defenses of coral reef organisms
P173

The genomics and transcriptomics of immunity and the coral 'holobiont'

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Genomics and transcriptomics can be used to identify evolutionarily conserved genes, as well as previously unidentified species-specific genes. But the challenge of genomics is how to go about identifying these genes, what to do with all of this information, and how this information ultimately be used in conservation setting. In order for the coral organism to co-exist with the bacteria, fungi, and zooxanthellae symbionts, there must be immune recognition or suppression occurring between the coral host and the accompanying symbiotic organisms. Using *Pocillopora damicornis* as a model, a 454 stress transcriptome was developed from the adult coral holobiont, including transcripts pooled from heat shock, dessication, and hyposaline stress. This transcriptome has subsequently been used as a scaffold to further identify transcripts in RNAseq experiments. Using these datasets, I will examine what potential immune response genes are present in *P. damicornis*, and the potential ramifications for conservation. All of these transcripts have been housed in the publically available database www.Pocilloporabase.org.

16C Immune defenses of coral reef organisms
Friday 13 July, 1015, MR3

16D Functional roles of microbes in reef ecosystems

Microbial buffering: protecting the Great Barrier Reef against anthropogenic impacts

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Coral reefs are productive and diverse ecosystems but are declining worldwide due to human activities such as fishing and agriculture. The Great Barrier Reef (GBR), an iconic Australian resource, is protected from fishing but is susceptible to the agricultural fertilisers and pesticides found in runoff waters. Microorganisms are an essential part of coral reef ecosystems, encode a large array of enzymes and have rapid generation times. We thus hypothesise that microorganisms can degrade pesticides and recycle nutrients found in land-based anthropogenic runoff, thus protecting the GBR against human-induced stresses. During 2 years, samples were collected in the GBR lagoon along a 120 km transect exposed to a gradient of runoff water and for which extensive metadata exists. The profiling of microbial communities through 16S rRNA sequencing revealed that the microbial composition changed significantly between the dry season and the wet season (during which runoff is more abundant). We also found that microbial communities close to the runoff source were enriched in Thermoplasmatales, a group of Archaea previously found in association with corals. This suggests that specific microorganisms effectively buffer the reef from anthropogenic runoff. Phages, viruses of bacteria, may be promote a quick adaptation of these microorganisms to floodwaters by laterally transferring beneficial genes. To complement the 16S rRNA profiling, we have thus started viral and microbial metagenomic analyses which will identify which genes are important to degrade pesticides and recycle nutrients in the GBR lagoon.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1515, MR3

Microbial contribution to competition between corals and benthic algae

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Competition between reef building corals and benthic algae is of key importance for reef dynamics, and these interactions occur on spatial scales ranging from chemical to regional. Using a combination of underwater surveys, experimental manipulations, oxygen microprobes, and metagenomics, we examined natural interactions between the reef-building coral *Montastraea annularis* and benthic algae. The macroalgae *Dictyota bartayresiana* and *Halimeda opuntia*, as well as a mixed consortium of turf algae, caused hypoxia on the adjacent coral tissue which was relieved when the algae were removed. Turf algae were also associated with major shifts in the bacterial communities at the interaction zones, including more pathogens and virulence genes. In

contrast to turf algae, interactions with crustose coralline algae (CCA) and *M. annularis* did not appear to be antagonistic at any scale. These zones were not hypoxic, the microbes were not pathogen-like, and the abundance of coral-CCA interactions was positively correlated with percent coral cover. We propose a model in which fleshy algae (i.e. some species of turf and fleshy macroalgae) alter benthic competition dynamics by stimulating bacterial respiration and promoting invasion of virulent bacteria on corals. This gives the algae a competitive advantage over corals, particularly when human activities such as overfishing and eutrophication remove controls on algal abundance. Together, these results demonstrate the intricate connections and mechanisms that structure coral reef communities.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1700, MR3

Metagenomic analysis of the microbial community associated with *Lophelia pertusa*

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Lophelia pertusa, a cosmopolitan cold-water coral, forms vital reef habitats for many deep-sea fishes and invertebrates. Studies of the microbial communities that support the growth and health of *L. pertusa* have relied on culture- and PCR-based assays. Complementing these methods with a metagenomic approach gives a broader overview of diversity and function of the microbial community of these corals. Two *L. pertusa* samples, one each from the Gulf of Mexico and western Atlantic Ocean, were collected via submersible and fixed in RNALater. DNA from the microbial-sized portion of the *L. pertusa* holobiont was extracted, amplified using multiple displacement amplification (Genomiphi), and sequenced on a 454 Titanium machine using FLX chemistry. Reads from both libraries were uploaded to MG-RAST, QIIME, and DeconSeq for quality control and analysis. Comparison of phylogenetic assignments of gene fragments in both libraries revealed a greater diversity of microbes than previously known, including similarities to microeukaryotes (fungi, nematodes) and a wide range of bacterial phyla. Unlike many shallow-water corals that are dominated by Proteobacteria, the principal similarities in the *L. pertusa* libraries were associated with the bacterial phylum Firmicutes. Further, the two *L. pertusa* libraries revealed the first measure of archaeal diversity in these corals. This work also provides the first insight into viruses associated with deep-sea corals, including similarities to marine phages and ssDNA and dsDNA eukaryotic viruses. These data represent the first metagenomic analyses of any deep-sea or cold-water coral and comparisons to microbes associated with shallow-water tropical corals.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1755, MR3

***In situ* coral-bacteria interactions reveal potential mechanism of resilience**

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In situ coral-bacteria interactions at the microscale remain largely unexplored, but they are critical in understanding the response of the holobiont to environmental stresses. Here, we test the hypotheses that bacteria associated with coral (*Pocillopora damicornis*) are subject to tight regulation of population size and that mechanisms exist to counteract excess bacterial growth stimulated by organic inputs. We employed high-speed laser scanning confocal microscopy (LSCM) on live coral as well as microfluidics to constrain these hypotheses. We also tested a coral pathogen's (*Vibrio coralliilyticus*) potential to evade such regulation. The results of two independent experiments showed that bacterial abundance on the coral surface was not sensitive to organic matter enrichment (5 mg/ L peptone), and that enriched corals released significantly more bacteria from their surfaces than control corals ($p < 0.01$; $35.9 \pm 1.4 \times 10^5$ cells/cm^2 versus $1.3 \pm 0.5 \times 10^5$ cells/cm^2). In the case of *V. coralliilyticus*, we observed a dose-dependent response that suggested a behavioral regulation of the association, possibly by both the bacterium and the coral. We are currently applying microfluidic devices to elucidate the underlying interaction mechanism. Our results support the hypothesis that shedding bacteria from the mucus layer may be an important mechanism by which corals regulate associated bacterial abundance under organic matter stress, but that some pathogens may evade regulation under certain conditions. Additionally, the ability to observe this behavior in real-time at the microscale, using LSCM and microfluidics, opens an unexplored avenue for mechanistic studies of coral-microbe interactions.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1530, MR3

Comparative genomic analysis of *Nematostella vectensis* microbial symbionts

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Nematostella vectensis, the starlet sea anemone, is fast becoming a powerful model for studying the host-microbe interactions of cnidarians in particular and Eumetazoans in general. We have observed through culture-independent analysis of 16S rRNA gene diversity that *N. vectensis* is associated with similar populations of microbes when sampled over distinct geographic locations. While these culture-independent methods corroborate the existence of stable bacterial associates, they reveal nothing of the potential functions of these symbionts within their anemone host, nor do they indicate mechanisms with which these microbes could be using to associate. In order to begin to address these questions, the genetic repertoires of 10 selected microbial strains from the *N. vectensis* holobiont were determined by whole-genome sequencing. Comparisons of the genomic compositions of these sequenced strains, both among each other and to sequenced reference genomes, reveal conserved genetic characteristics among the symbionts that could explain their ability to successfully associate and interact non-pathogenically within their anemone host. Notably, differences in the distribution of Type III secretion systems, amino acid transporters, and transcriptional stress response activators between holobiont associates and closely related reference genomes may reveal adaptations to the holobiont that permit stable association. An analysis of shared gene content between these sequenced strains and the sequenced genome of *N. vectensis* did not support a role for lateral gene transfer between microbial associates and the *N. vectensis* genome, and suggests these stable microbial associates are a likely source of contamination of bacterial DNA in the *Nematostella* genome.

16D Functional roles of microbes in reef ecosystems P174

Effects of iron enrichment on microbial and viral benthic communities

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Iron inputs from shipwrecks have been implicated in persistent community shifts in remote, iron-limited coral reef systems. Shipwreck debris on coral reefs in the Line Islands has resulted in increased algal turf cover with a concomitant decline in crustose coralline algae and coral cover. These reefs appear black because of their dark-colored benthos and reduced water clarity, and are thus referred to as 'black reefs'. Elemental analysis of mixed algal communities from black reefs suggests that increased availability of iron contributes to algal overgrowth. Iron concentrations (measured using ICP-OS) were 6 X higher in algae from the black reefs on Millennium Atoll than from reference reefs on Millennium and other Line Island reefs. Metagenomic sequencing revealed increased prevalence of iron-associated virulence genes in microbial communities associated with the black reef on Millennium Atoll. Corals incubated with coral rubble from black reef areas exhibited higher mortality, compared to treatments without rubble or with the addition of antibiotics. Coral mortality was exacerbated by the addition of iron, further linking microbial activity to the degrading coral health observed on black reefs. To further investigate the effects of iron enrichment on benthic microbial and viral communities, we are currently analyzing metagenomic libraries from two other black reefs in the Line Islands. This follow-up study will help to further elucidate whether iron enrichment promotes changes invirulence, composition, and metabolic function of these communities.

16D Functional roles of microbes in reef ecosystems P175

Resilience of the coral holobiont: dynamic interactions between coral commensal bacteria and opportunistic pathogens

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A multi-host opportunistic pathogen, *Serratia marcescens,* is a causative agent of white pox disease in *Acropora palmata*. Early events in the infection by the pathogen involve attachment and colonization of mucous surfaces of the host. We hypothesized that this opportunistic pathogen relies on specific virulence genes and behaviors to establish within the coral's surface mucopolysaccharide layer and to infect the coral host. To colonize semi-solid surfaces, *S. marcescens* PDL100 utilizes both swarming motility and biofilm formation. The same behaviors are also known to be correlated with virulence of pathogens. We further hypothesized that coral commensal bacteria can disrupt some of these behaviors. Isolates of *Marinobacter* sp. inhibited both biofilm formation and swarming in *S. marcescens* PDL100, without affecting growth of the coral pathogen, indicative of the production of multiple inhibitors, likely targeting lower level regulatory genes or functions. The

progression of a disease caused by *S. marcescens* in a model polyp *Aiptasia pallida* was inhibited by a six-species cocktail containing corals commensals capable of inhibiting swarming or biofilm formation. An Î-proteobacterial isolate, capable of inhibiting biofilm formation had a similar effect. Members of the coral commensal microbiota inhibit swarming motility and ß-galactosidase, a catabolic enzyme strongly induced in PDL100 during growth on coral mucus. These results demonstrate that coral commensal bacteria are capable of inhibiting specific virulence-related behaviors in opportunistic pathogens within the same ecological niche with potential implications for the health of corals and reef ecosystems.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1500, MR3

Identification of antimicrobial compounds produced by coral associated bacteria

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Coral associated bacterial communities are known to produce antimicrobial compounds potentially inhibiting the colonization and growth of other invasive species and potentially pathogenic species. To date, none of these compounds responsible for this antimicrobial activity have been isolated and characterized. Here, we report the first identification of antimicrobial compounds produced by coral associated bacteria. Bacteria were isolated from the tissues of three species of scleractinians corals (*Acropora millepora, Montipora aequituberculata* and *Pocillopora damicornis*) and belonged to the genera *Ruegeria, Pseudomonas, Pseudovibrio* and *Pseudoalteromonas*. All the strains were selected due to their demonstrated abilities to degrade dimethylsulfoniopropionate (DMSP), a sulfurous molecule suspected to play a role in structuring coral-bacteria associations. All strains inhibited the growth of the coral pathogen *Vibrio coralliilyticus* (the causative agent of White Syndrome in the Indo-Pacific) and a newly identified marine pathogen *V. owensii* in agar diffusion assays. Flash column chromatography and HPLC were used to isolate the antimicrobial compounds and spectroscopic techniques including nuclear magnetic resonance spectroscopy (NMR) and mass spectrometry (MS) enabled their identification. One of the antimicrobial molecules identified was thiotropocin, a sulfur-containing antibiotic likely derived from DMSP catabolism. Thiotropocin was produced in large amount by *Pseudovibrio* spp. and prevented the growth of *V. coralliilyticus* and *V. owensii* at very low concentrations (<1µg/ml). These results provide further evidence for the integral role of DMSP in structuring coral associated bacterial communities and the ability of these communities capable of metabolizing DMSP, to contribute to coral disease prevention.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1545, MR3

Disruption of AHL signalling within corals during thermal stress

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Bacteria utilise N-acylhomoserine lactones (AHLs) to modulate behaviour on a population level. This 'Quorum Sensing' is widespread amongst bacteria and modulates the expression of multiple genes, including those involved in motility, biofilm formation and maintenance and the production of exoenzymes including antimicrobial agents; all processes that would be expected to have a significant role in structuring microbial communities. Corals harbour specific microbial communities which are thought to confer resistance to the host by production of antimicrobial agents, which are compromised by disease. Incidences of coral disease have often been linked to increases in temperature. AHL signal molecules are also sensitive to temperature, undergoing hydrolysis of the lactone ring as temperature increases. The link between increased temperature, AHL signalling and changes to coral-associated microbial communities was investigated using *Stylophora pistillata* from the Red Sea. Using the *Agrobacterium tumefaciens* NTL4 AHL bioreporter and thin layer chromatography, AHL profiles from wild and aquaria maintained coral tissue were compared, revealing the presence of conserved signalling profiles. Further experiments established the degradation of the conserved signalling profile found in *S. pistillata* after 7 days exposure to temperature stress. Changes to the bacterial community were investigated using both DGGE and 16S rRNA tagged 454 pyrosequencing. Sequence data reveal an increase in known AHL-degrading bacteria with increasing temperature. Further studies of the effect of temperature on bacterial isolates again reveal changes to signal production and signal degradation with increasing temperature. This data indicates a possible link between temperature stress and disturbance to coral-associated bacterial communication.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1630, MR3

Coral mucus-associated pseudoalteromonas with antibacterial activity

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The coral mucus layer contains ecological niches rich in nutrients and displaying diverse bacterial populations. Interactions among microorganisms found in coral mucus may be mutualistic or antagonistic. Coral mucus-associated bacteria are thought to play a role in coral health and immunity, possibly through production of antimicrobial substances. To assess this possibility, selected microorganisms isolated from the mucus layer of several coral species were grown on agar plates. Screening for antimicrobial substances was performed using overlay and drop techniques, utilizing several indicator microorganisms. The effect of different temperatures on antibacterial activity was also tested. Results indicate that 25%-70% of cultivable mucus-associated bacteria from scleractinian corals demonstrated bioactivity. Higher percentages of activity were evident in mucus-associated cultivable bacteria from massive and solitary corals, when compared with bacteria from branching or soft corals. In some cases, inhibitory effects were confined to the cell fraction, suggesting the presence of cell-bound substance(s), sensitive to temperature and most likely proteinaceous in nature. Isolates related to the genus *Pseudoalteromonas* demonstrated antibacterial activity against Gram-positive bacteria, including marine isolates from different coral species. These isolates secrete active compounds not sensitive to proteases, and demonstrating partial resistance to heat treatment. *Pseudoalteromona*s cell-free supernatant (CFS) inhibited growth of tester strains. CFS extracts demonstrated complete inhibition of tester-bacteria growth, whereas CFS demonstrated only partial inhibition. These results demonstrate the existence of microorganisms with antimicrobial activity on the coral surface in particular in the protective mucus layer, indicating that they may play a role in protecting the coral host against pathogens.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1715, MR3

***Aiptasia pallida*: a model for the studies of polyp-microbe interactions**

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Model organisms are instrumental for understanding the mechanisms of interactions between pathogens, hosts and host-associated microbiota. Adopting *Aiptasia pallida* as such a model could positively impact coral disease research, as well as our understanding of the interactions within coral-associated microbiota. We demonstrated that *A. pallida* is susceptible to infections with *Serratia marcescens* PDL100 (a causal organism of the white pox of Caribbean acroporid corals), *Vibrio shiloi, V. coralliilyticus*, a consortium of vibrios associated with the yellow band disease and a polymicrobial black band disease consortium. Under the tested conditions, polyp bleaching was not observed in the presence of pathogens; however, we documented dose-dependent die-off of the polyps. Treating polyps with commercially available antibiotics (or their cocktail) did not reliably clear native bacteria from the polyps reared in aquaria. Nevertheless, addingbacteria isolated from coral surfaces affected the outcome of the interactions with pathogens. Specifically, the addition of a γ-proteobacterium or a six-strain cocktail of *Marinobacter* spp and γ-proteobacteria prevented the die-off of polyps challenged with *S. marcescens* PDL100. This demonstrates that the composition of polyp-associated microbiota could be manipulated under the laboratory conditions. While it remains to be established whether *A. pallida* responds to pathogens similarly to corals, these studies demonstrate the utility of this weedy polyp as a surrogate model for the studies of coral disease and the interactions of coral pathogens with native microbiota.

16D Functional roles of microbes in reef ecosystems
P176

Chemotaxis by coral reef bacteria

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Bacteria play a fundamental role in determining the health and ecology of coral reefs, but the

ecological mechanisms underpinning coral-bacteria associations are not fully characterised. To examine the potential role of chemotaxis in the ecology of coral reef bacterial communities, we performed a suite of laboratory and field-based experiments to test the extent of chemotaxis towards organic substrates known to occur within the coral microenvironment. Chemoattractants tested included several amino acids, sugars, zooxanthellae exudates and dimethylsulfonopropionate (DMSP). Strong chemotactic responses towards several of these chemoattractants were observed. Coral reef-associated bacteria, collected from Heron Island on the Great Barrier Reef, typically exhibited significantly higher levels of chemotaxis than bacteria collected from open water in a lagoon adjacent to the reef. In laboratory experiments, DMSP as well as the amino acids tryptophan, aspartic acid and casamino acids invoked the strongest chemotactic responses. We also employed a novel, microfluidics-based *in situ* chemotaxis assay to investigate chemotactic responses by bacteria associated with the surfaces of the coral *Pocillopora damicornis*. With the aid of 16S rRNA pyrosequencing, we identified significant differences in the composition of the microbial assemblage responding to different attractants, indicating that different infochemicals are employed by specific members of the coral-associated bacterial community. Our observations indicate that chemotaxis may be an important behaviour within the complex associations between corals and bacteria.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1745, MR3

Red Sea *Acropora squarrosa* bacterial population dynamics under adverse anthropogenic conditions

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Reef-building corals are cornerstones of life in the oceans. Understanding their interactions with microorganisms and their surrounding physicochemical conditions is important to comprehend reef functioning and ultimately protect coral reef ecosystems. Corals associate with a complex and specific array of microorganisms that supposedly affect their physiology and therefore can significantly determine the condition of a coral ecosystem. As environmental conditions may shape bacterial diversity and ecology in the coral symbiosis, ecosystem changes might have unfavorable consequences for the holobiont, yet the likliehood of this possibility is poorly understood. Here, we are in the process of analyzing microbial community changes in *Acropora squarrosa* as a consequence of induced eutrophication and overfishing over 16 weeks by using *in situ* caging and slow release fertilizer treatments in an undisturbed Red Sea reef (22.18°N, 38.57°W). We use16S rRNA amplicon sequencing to evaluate the individual and combined effects of over-nutrification and fishing pressure, 2 of the most common local threats to coral reefs. We aim to better understand bacterial population dynamics under anthropogenic influences and its role in coral resilience. Furthermore, this data will be useful to better predict the consequences of human activity on reef ecosystems.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1750, MR3

Effect of gene transfer agents on bacteria and coral larvae

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Horizontal gene transfer via gene transfer agents (GTAs) has only recently been shown to occur with high frequency in the oceans. For instance, the environmental gene transfer frequency for the bacterium *Ruegeria* sp. via GTAs has been shown to be up to hundreds of million times greater in comparison to spontaneous transformation. The ecological significance of it; however, has not been determined. Here, we inoculated *Porites astereoides* coral larvae with GTAs from *Ruegeria* sp., which resulted in a significant increase of coral larvae settlement in comparison to control samples. We are currently sequencing the transcriptomes and metatranscriptomes of coral larvae and bacterial biofilms (used as settlement substrate) to determine the effect of GTAs on coral and bacterial gene expression and bacterial community composition. Furthermore, we plan to determine actively expressed genes that were transferred via GTAs by back-mapping metatranscriptomic data to the *Ruegeria* sp. genome sequence. We anticipate that this work will shed further light on the significance of GTAs to marine ecosystems.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1645, MR3

Interactions between nutrient addition, herbivory, and the coral microbiome

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Corals contain extensive microbial diversity. In addition to populations of eukaryotic *Symbiodinium* symbionts, corals also harbor distinctive communities of bacteria, bacteriophage, fungi, and viruses. We hypothesize that these complex microbial consortia play a role in mediating the effects of human impacts such as overfishing or agricultural runoff on coral health. To address this question, we are analyzing data from a multi-year *in situ* experimental intervention. The top-down ecological effects of herbivore removal (e.g. from overfishing) are tested by enclosing coral subplots with cages, while the bottom-up effects of inorganic nitrogen and phosphorous addition (e.g. from agricultural runoff) are tested by addition of a nail carrying a fertilizer diffuser. Both interventions are matched to controls (three-sided cages or nails without diffusers) in a fully crossed study design. So far, >1600 coral mucus DNA samples from 3 coral taxa (*Porites asteroides, Siderastrea siderea, Agaricia* sp.) have been collected from 4 replicate plots since July 2009. DNA samples are accompanied by extensive metadata including water temperature, irradiance, coral health (weight, extent, coloration, predator scar density), algal cover, and concentrations of inorganic nitrogen and phosphate. Microbial communities are being analyzed using both an initial T-RFLP analysis (for comparison with previous coral samples), and subsequent high-throughput metagenomic and marker gene (16S rRNA and 18S rRNA) techniques. Preliminary analysis indicates that: (i) *Porites asteroides* and *Siderastrea siderea* contain distinct bacterial communities and (ii) cage enclosure and nutrient addition increase algal cover and alter microbial community composition.

16D Functional roles of microbes in reef ecosystems
Tuesday 10 July, 1730, MR3

Theme 17. The Coral Triangle Initiative

17A Science to support the Coral Triangle Initiative

Marine resource management data gaps in the Coral Triangle

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For the past 3 years the Coral Triangle Atlas has been building an online GIS database for planning marine resource management of the Coral Triangle. Data was collected from international NGOs and government agencies representing key spatial layers used to design marine protected area networks; specific requests from scientists and managers; and measures of success in the Coral Triangle Initiative Regional Plan of Action. A gap analysis of layers from 4 categories - habitats, biodiversity, threatened species and threats - identified data poor areas at a regional management scale. It can be argued that the gap in information influences the design of MPA networks and choices on investing conservation money. Nevertheless, in order to implement timely conservation actions, managers are required to make the best decisions possible with available data. We demonstrate several ways of addressing data gaps, for example, identifying proxies, incorporating expert knowledge, using global analysis, or investing in additional data. We also identify the limits and trade-offs associated with alternatives that affect confidence in conservation decisions and raise the question of whether time and money would be better invested in improving data.

17A Science to support the Coral Triangle Initiative
Monday 9 July, 1530, Sebel Bluewater

Linking research to Indonesia's CTI action plan: the SPICE program

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The Indonesian-German program Science for the Protection of Indonesian Coastal Ecosystems (SPICE) has been an umbrella for joint research projects since 2003. In 2012, SPICE will enter its third phase. The 12th ICRS thus presents a unique opportunity to link activities within the program to other initiatives in the area. As a bilateral initiative, one focus of SPICE has been to examine topics with policy relevance for Indonesia, such as environmental change and governance in the Segara Anakan Lagoon in Java, or reef fisheries and marine management in the Spermonde Archipelago near Makassar, Sulawesi. Research in Spermonde has examined the implementation of community-based MPAs within the frame of the Coral Reef Rehabilitation and Management Program (COREMAP). Results have been presented to regional policy makers at a workshop in Makassar, and to international audiences during the World Ocean Conference 2009 in Manado. Yet, the link to parallel activities, in particular by NGOs, and to regional initiatives such as the CTI needs strengthening in order to increase the effectiveness and policy impact of SPICE activities. During the third phase, SPICE strives to better align with other research as well as policy initiatives, in particular by contributing to two goals of the Indonesian CTI National Plan of Action - applying an ecosystems approach to fisheries management, and effectively implementing and managing MPAs. We present SPICE results with relevance to these two goals, and introduce research activities planned until 2015. We conclude by identifying research gaps in addressing CTI goals and strategic areas for collaboration.

17A Science to support the Coral Triangle Initiative
P178

Solving the mystery of marine protected area performance: methodologies for linking governance to ecological and social outcomes

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Marine protected areas (MPAs) are integral strategies for local, national, and international coral reef conservation, but their contributions to biodiversity protection and poverty alleviation remain a contentious policy debate. Advocates tout MPAs as a win-win strategy, while critics argue that MPAs place the welfare of fish above the well-being of impoverished fishing communities. Rigorous evidence is lacking to

explain why under certain conditions, MPAs can provide both biodiversity and social benefits, while in other settings trade-offs exist between the two. To better understand these variations, we present baseline data on an MPA network in the Bird's Head Seascape of Indonesia. Here, a multidisciplinary initiative has been established to document the ecological and social impacts of coral reef MPAs, explain variation in these impacts, and provide insights for policy and future research. Using existing ecological monitoring data collected through collaborations between conservation non-governmental organizations, and governance and social data from newly-developed impact evaluation research protocols, we introduce methods in data analysis that have the potential to link differences among conservation interventions (i.e., MPA governance) to differences in conservation outcomes (ecological and social). Interdisciplinary analysis may offer an opportunity to better understand social and ecological linkages, but its utility is constrained by the lack of a robust regional monitoring program, which presents challenges for data management and analysis. We recommend expanding ecological monitoring to include matched comparison (non-MPA) sites, stronger coordination on database design and management, and a marine parallel to the International Forestry Resources and Institutions as a way forward.

17A Science to support the Coral Triangle Initiative
Tuesday 10 July, 0930, Sebel Bluewater

Incorporating climate change into ecosystem approaches to fisheries management

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The impacts of climate change and ocean acidification on the small-scale fisheries of tropical, near shore waters are poorly understood and of great concern for the food security and poverty reduction of the 120 million coastal dwellers in the Coral Triangle that depend on them. The coral reefs and associated ecosystems that support the majority of these small-scale fisheries occur predominantly in densely populated, developing countries and provide important sources of income and subsistence nutrition. Reef systems are vulnerable to thermal stress (e.g., coral bleaching and mortality), CO_2-induced ocean acidification (e.g., reduced calcification of corals and other calcifiers, enhanced reef erosion, and changing community composition), sea level rise (e.g., increased erosion/sedimentation onto coral reefs), changing ocean circulation patterns (e.g., larval connectivity and upwelling patterns), and changing storm frequencies and intensities (e.g., wave-induced habitat destruction and precipitation-induced flooding). Climate change and ocean acidification are expected to decrease and modify patterns of fisheries production, affect human health, and damage or destroy coastal infrastructure and habitats. Since the uncertainties brought about by climate change may reduce incentives for long-term management of coastal resources, there is an increasingly urgent need to better understand the likely impacts of climate change and ocean acidification on tropical, near shore, small-scale fisheries and provide guidance on developing governance strategies to integrate understanding of these impacts into ecosystem approaches to fisheries management (EAFM). This paper reports findings from an expert workshop that examined climate vulnerability assessment approaches and developed guidelines to incorporate climate change and ocean acidification considerations into EAFM policy frameworks.

17A Science to support the Coral Triangle Initiative
Monday 9 July, 1545, Sebel Bluewater

Community driven co-management at the scale of seascape

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There are many examples across Indonesia and the Coral Triangle of both large-scale national MPAs and very small-scale community managed marine reserves. However, there are few examples of successful co-management systems that actively integrate communities within the management of larger scale MPAs. The Bird's Head Seascape (BHS) located in West Papua, Indonesia, offers a model of a large-scale ecologically-connected multiple-use MPA network on a sufficient scale to regenerate local subsistence and artisanal fisheries. Yet it is co-managed in a way that integrates modern and traditional community management systems and prioritizes community-based management principles. With 12 MPAs in the network, covering over 3.5 million ha, the BHS MPA network represents over 25% of the Indonesia National MPA network. The network combines both national level MPAs and local regency declared and managed MPAs within a coordinated management system that ensures efficiency and consistency while maintaining flexibility to

address local opportunities and constraints. Key lessons from the first 6 years of MPA development and implementation in the BHS are presented here including: strategies for making MPAs vehicles of political and cultural empowerment; the incorporation of ecosystem-based approaches to management; the cultivation of strong, well-respected local leaders as MPA practitioners through long-term mentoring and capacity building; and the development of effective joint enforcement systems for large MPAs. We present a model that demonstrates how co-managed MPAs can be applied at the seascape level to achieve both biodiversity protection and fisheries management to support long-term food and livelihood security of local people.

17A Science to support the Coral Triangle Initiative
Monday 9 July, 1630, Sebel Bluewater

Informed opportunism for conservation planning in the Solomon Islands

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Human factors more than ecology dictate conservation opportunity and the subsequent success of implementation. This is particularly true in places such as the Solomon Islands, where most terrestrial and coastal marine areas remain in community ownership. However, factors such as community support are not reliably predictable, nor easy to map, and are therefore challenging to incorporate into systematic conservation plans. Here, we describe how the Lauru Land Conference of Tribal Communities and The Nature Conservancy have worked with the communities of Choiseul Province, Solomon Islands, to develop a conservation planning process that reconciles community-driven conservation opportunities, with a systematic and representation-based approach to prioritization. We suggest how sophisticated prioritization software can be used collaboratively in a community setting to dynamically assess and guide conservation opportunities as they arise-- a process of informed opportunism.

17A Science to support the Coral Triangle Initiative
Tuesday 10 July, 0945, Sebel Bluewater

A high-resolution regional model for the Coral Triangle

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We present results from a recently developed, high-resolution, regional ocean circulation model of the Coral Triangle. The model was implemented to investigate the vulnerability of reef communities to bleaching events. Conservation efforts within the Coral Triangle Initiative are interested in understanding how the oceanographic circulation influences the susceptibility of coral reefs to bleaching as well as their ability to recolonize via larval-dispersal following bleaching events. The physical complexity of the Coral Triangle region requires a high-resolution model that can capture the spatial and temporal variability of the oceanographic circulation in the region. Our model of the Coral Triangle is based on the Regional Ocean Model System (ROMS). ROMS is a state-of-the-art, three-dimensional model that includes tidal forcing. The CT-ROMS implementation has a spatial resolution of ~5 km and a time-step of 90-sec. We will present results from a multi-decadal simulation of the complex circulation patterns in this area and show how these patterns respond to climate forcing. We emphasize the Indonesian Throughflow (ITF), the major pathway for water exchange between the Indian and Pacific Oceans. The decadal variability of the various (modeled) branches of the ITF will be presented, as well as the ability of the model to accurately simulate sea surface temperature. Preliminary results of reef connectivity, based on Lagrangian particle tracking, will also be presented with an emphasis on how larval dispersal patterns vary in response to climate variability.

17A Science to support the Coral Triangle Initiative
Monday 9 July, 1515, Sebel Bluewater

Revealed: reef fish and coral habitat patterns, Bird's Head, Indonesia

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The Bird's Head Seascape in West Papua, Indonesia is recognized globally for its unparalleled marine biodiversity. However, scientific investigation of the region begun recently and is still in its infancy, as evidenced by findings of new species with each

expedition. The burgeoning network of marine protected areas (MPAs) in the region poses an opportunity to measure the effects of protection on coral cover and fish density and diversity. Here, we synthesize results from ecological assessments coordinated across conservation organizations (Conservation International, The Nature Conservancy, and WWF-Indonesia, along with key local institutions) to better understand underlying ecological patterns, as well as inform efforts to protect these threatened ecosystems. We examined habitat cover and condition, along with fish abundance, density, biomass, and diversity in 6 MPAs over a five-year period, providing a strong baseline. Multi-pronged methods for fish surveys target different taxa of interest. Hard coral cover averages 20-40% across the seascape, varying by MPA and also by survey method: estimates are consistently lower for manta tow swims when compared with point intercept transects. Although the monitoring program is well-designed and well-funded, scaling up from site-level analysis to region-level analysis remains challenging. Looking ahead, the region would benefit from stronger data coordination and inclusion of study sites outside the boundaries of MPAs to serve as controls for these policy experiments. This system would allow better understanding of which characteristics of protected areas design and governance are most influential in conserving ecosystem function and biodiversity.

17A Science to support the Coral Triangle Initiative
Monday 9 July, 1715, Sebel Bluewater

Monitoring coral reef governance in the Birds Head Seascape, Indonesia

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Researchers and practitioners have long recognized that marine resource governance impacts ecosystem integrity and human well-being. But attempts to explore these relationships have been hindered by the absence of robust, replicable, theory-based methods of measuring and characterizing governance structures and processes. Building upon an analogous system developed by Nobel laureate Elinor Ostrom to characterize forest governance, we developed research protocols that allow us to characterize governance structures and processes in marine protected areas (MPAs) and other spatially-explicit marine governance regimes. Drawing upon focus groups and key informant interviews, these protocols provide quantitative and qualitative data regarding decision-making arrangements, resource use rights, monitoring and enforcement systems, and conflict resolution mechanisms. Pilot results from 19 focus groups and 49 key informant interviews at 2 coral reef MPAs in the Bird's Head Seascape of Tanah Papua, Indonesia, demonstrate the potential of this approach to systematically capture comparable data that illustrate meaningful differences in governance among MPAs, and between MPAs and non-MPA governance systems. High response rates and low error rates highlight the potential for these research instruments to be employed effectively by relatively inexperienced researchers working in highly impoverished and marginalized rural communities. Based on pilot results, we have subsequently refined our instruments and anticipate scaling up our monitoring efforts in Indonesia and elsewhere, in order to gain further scientific insights into the essential links between MPA governance and impacts.

17A Science to support the Coral Triangle Initiative
Monday 9 July, 1645, Sebel Bluewater

An ecological and social approach to Banggai cardinalfish conservation management

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The Banggai cardinal fish (*Pterapogon kauderni*, Koumans 1933), often called BCF, is a restricted range coral reef associated fish endemic to shallow waters (under 5m) around the Banggai Archipelago, Indonesia. Listed as 'Endangered' in the IUCN Red-List, the international marine aquarium trade and habitat degradation are considered major threats. After the (unsuccessful) proposal for listing under CITES Appendix II in 2007, a national BCF Action Plan was developed and conservation of *P. kauderni* is a goal of the Indonesian Coral Triangle Initiative National Plan of Action. A district MPA established in 2007 by decree of the Banggai Kepulauan District Head, consisting of a network of 10 islands, is still in the planning stage. For 2 islands, including Banggai Island, site of the main BCF fishing grounds, *P. kauderni* conservation is the main management target. With no pelagic phase and high site fidelity, the Banggai cardinal fish exhibits a level of genetic structure unusual in a marine fish, indicating that management units should be based on genetically determined sub-populations (stocks). The results of current research to identify and characterise these units from biological, ecological and socio-economic aspects will be presented. The data will be managed within a GIS database using spatial analysis applications including MARXAN to provide management support data

and tools. In particular, science-based zoning options with management units/targets based on genetic population structure and GIS will allow evaluation the conservation effectiveness of options put forward by stakeholders.

17A Science to support the Coral Triangle Initiative
P179

Moving toward regional ocean governance,the Coral Triangle Initiative

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This study investigates the emergence of regional governance regimes that can enable and support integrated approaches for managing marine resources and ecosystem services. The current unsustainable trajectory for marine social-ecological systems necessitates a transformative change of governance. In particular, there is a pressing need for new international institutions and partnerships for dealing with pressure from global drivers, particularly given the interconnections between issue areas such as climate change, food security, ocean acidification and biodiversity. Currently these are addressed by separate organizations, policies and institutions. The Coral Triangle Initiative (CTI) is a regional governance initiative with 5 project goals: climate change adaptation, ecosystem-based fisheries management, marine protected areas, well-managed seascapes, and protection of threatened species. Although the CTI presents a unique window of opportunity, linking and coordinating between levels and integrating project goals is crucial in order to shift to a sustainable trajectory. We use insights from resilience thinking and transformation of social-ecological systems to analyze these dynamics. The paper focuses on the social networks of actors involved in the CTI and more specifically 1) their ability to reconfigure actor networks to address the interacting project goals and 2) their capacities to combine formal and informal channels to coordinate actions across levels to develop integrated forms of marine stewardship. Finally, the paper provides recommendations on the specific processes and mechanisms for navigating a regional governance transformation such as the CTI.

17A Science to support the Coral Triangle Initiative
Tuesday 10 July, 1000, Sebel Bluewater

Linkages between MPAs and social well-being: insights from Papua, Indonesia.

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Marine protected areas (MPAs) are an integral component of local, national, and international strategies for biodiversity conservation, but their impacts on human well-being remain contested. Advocates tout MPAs as win-win strategies for conservation and poverty alleviation, while opponents argue that MPAs place the welfare of fish above the well-being of impoverished fishing communities. To inform this debate, we are monitoring the social impacts of MPAs in the Bird's Head Seascape (BHS). Using a quasi-experimental design, we examine social well-being across 5 social domains: economic well-being, health, political empowerment, education, and culture. Baseline data from 6 MPAs provides insights on the social well-being of coastal communities in and outside the MPAs. In both MPA and non-MPA comparison communities, households have few material possessions and are highly dependent on marine resources. A high percentage of household protein is derived from the marine environment, but households are largely food secure. Enrollment in formal education is relatively high despite substantial levels of child morbidity and mortality. Residents have varying levels of control over marine resources, together with high but variable place attachment. The novel insights provided by baseline data in the BHS highlight the opportunity for rigorous social monitoring to inform adaptive management at the site, program, and policy levels. Future research will continue to follow these sites over time, enabling us to explore how MPA impacts vary within and among social groups as well as between social domains, providing a rigorous foundation for the analysis of protected area-poverty linkages.

17A Science to support the Coral Triangle Initiative
Monday 9 July, 1700, Sebel Bluewater

Applying marine habitat maps and biodiversity and resilience assessments to management

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The Khaled bin Sultan Living Oceans Foundation is conducting a 5-year Global Reef Expedition (GRE) to map, characterize and assess coral reefs, and develop tools and

information to assist local managers in their conservation and management activities. Measurements of coral demographics, mortality and recruitment are combined with assessments of benthic cover types, biomass of algal functional groups, population structure of commercially-valuable and ecologically-relevant reef fishes, and environmental resilience indicators using a standardized rapid quantitative survey protocol. Concurrent ground truthing is used to define the bathymetry, spatial distribution, and extent of different habitat types, dominant species assemblages, substrate types, and underlying geomorphology. Ground truthing assists in identifying habitat classes, and create high resolution habitat maps. The goals of the GRE are to 1) determine the status of habitat and species that create and help maintain the health of the habitat; 2) identify local and regional threats, causes, and potential strategies to mitigate impacts; and 3) characterize patterns of recovery from past disturbances. Data are compiled into a Geographic Information System (GIS) database with satellite imagery, habitat maps, and other GIS layers, resulting in a landscape-scale tool useful for marine spatial planning. Following completion of Caribbean assessments in May, 2012, the GRE is now focused on the Indo-Pacific, with assessments in the Coral Triangle proposed to begin in 2013. Examples of the outputs of the work from the Red Sea and Caribbean and potential application towards management are discussed.

17A Science to support the Coral Triangle Initiative
P180

Reefs at risk in the Coral Triangle

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In February 2011, the World Resources Institute released Reefs at Risk Revisited, the most detailed global assessment of threats to coral reefs undertaken to date, in collaboration with more than 25 leading research, conservation, and academic organizations. This high-resolution analysis evaluates both local and global (i.e., climate-related) threats to coral reefs in the present and future, as well as management effectiveness of MPAs and the likely socio-economic impact of coral degradation on nations and territories with coral reefs. Reefs at Risk in the Coral Triangle, which is planned for release in early 2012, draws on the data and results from the global Reefs at Risk Revisited analysis to produce a regional report that provides greater detail and additional information on the status of coral reefs in the 6 countries that comprise the Coral Triangle region. The report includes information on local and global threats to coral reefs in the present, as well as projections to 2030 and 2050, including national- and regional-level data, maps, and statistics. Assessments of MPA effectiveness and socio-economic factors provide insight for developing management strategies at the regional, national, and local scale. This summary is targeted towards decision-makers and conservation practitioners in the region who can use the data, maps, and information to influence policies and management plans related to coral reef protection. This presentation will include an overview of the major findings of Reefs at Risk in the Coral Triangle and highlight potential applications of the data and information.

17A Science to support the Coral Triangle Initiative
Tuesday 10 July, 1030, Sebel Bluewater

Integrating socio-ecological resilience into Bali's coral reef management

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Bali Province is home to many small scale, community-based, marine managed areas designed to protect coral reefs. We have initiated a program to connect them both socially and ecologically to form a network which also takes into account climate change impacts. Historically, Bali bleached twice in each mass bleaching event (1982-1983; 1997-1998; 2009-2010). Rapid response studies of bleaching impact showed that in 2009, bleaching impact was widespread across 120 km of Bali's coastline and affected up to 40% of corals and in 2010 affected up to 55%. Some sites bleached severely and stand out as highly vulnerable to thermal stress and could be used as early warning sites. Moreover, resilience studies have identified sites where increased management could increase reef resilience capacity. This information will be used to improve the design and management of resilient MMAs and MMA networks in Bali. In addition, we found that dive operators in Bali employ local staff (90% of their staff) and have no other sources of income, highlighting the importance of coral reefs to this area. Further, we found that the overall satisfaction of most divers was influenced more by factors other than the state of bleaching. These findings suggest a variety of ways dive companies can maintain diver satisfaction and financial viability

during bleaching events by engaging in broader efforts to protect reef condition and providing service amenities valued by tourists.

17A Science to support the Coral Triangle Initiative
Tuesday 10 July, 1015, Sebel Bluewater

U.S. interagency science and technology partnerships in the Coral Triangle

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Heightened attention is being paid to ecosystem services, the importance of conserving coral reefs, and the services they provide to society. However, what ecosystem services means in policy and in practice remains largely theoretical, and examples remain quite rare. Interagency science and technology partnerships between the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Agency for International Development (USAID) provide a rare example of protecting ecosystem services of coral reefs within federal and international policy and practice. Using the example of the interagency efforts in the US Coral Triangle Initiative Support Program (USCTI), this paper presents a model for connecting federal policy with international conservation practice in conserving food security, biodiversity and human health and well-being. Recognizing the global importance of the Coral Triangle Initiative (CTI) in protecting marine biodiversity and food security in this geopolitically significant region, the U.S. has offered considerable financial, political and technical support, primarily through USCTI - the $42 million, 5-year program funded by USAID and the Department of State. Through US CTI's expansive local, national, and international partnerships, NOAA and partners aim to improve the management of millions of hectares of the Coral Triangle's coastal and marine ecosystems to protect food security and strengthen resilience to climate change for the Coral Triangle's 363 million people. From USCTI's transformative outcomes is emerging a new era of NOAA/USAID science and technology cooperation, and may be a model for ecosystem services for US and international policy.

17A Science to support the Coral Triangle Initiative
Monday 9 July, 1500, Sebel Bluewater

Genetic structure of *Culcita novaeguineae* pincushion starfish and secondary contact in the Coral Triangle

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The Coral Triangle is the centre of marine biodiversity and species richness tends to decrease from this region eastward across the Pacific Ocean and westward across the Indian Ocean. Because Pleistocene fluctuations in sea level potentially restricted gene flow between the 2 oceans, many invertebrate species experienced lineage diversification between the 2 oceans according to the mitochondrial haplotype analysis. Subsequent sea level rise may have caused secondary contact between the 2 diverged lineages resulting in high genetic and species diversities in this region today. However, there are few studies that examined how these two genetic lineages made the secondary contact and whether the two different lineages and/or species kept their identity or caused hybridization in the Coral Triangle. In order to elucidate how these 2 genetic lineages from the Pacific and Indian Oceans are mixed in the Coral Triangle, we sequenced the mitochondrial COI regions as well as nuclear intron of the pincushion starfish, *Culcita* sp., which is one of the common coral reef species of starfish. We found a deep genetic break between the Indian Ocean samples (from Thai Indian Ocean side) and Pacific Ocean samples (from Palau, Japan and northern Philippines) in the mitochondrial analysis. While the middle side of the Indonesian populations (Manado, Palu and Bontang) had Pacific mtDNA haplotypes, western Indonesian and north Jakarta populations had both Indian and Pacific haplotypes, showing a sign of secondary contact, suggesting that the two genetic lineages are sympatrically related in the northern part of Jakarta.

17A Science to support the Coral Triangle Initiative
P181

17B Marine Protected Areas and networks in the Coral Triangle

RESTORED strategies utilized for MPA support network processes

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We used the RESTORED (Resiliency, Effectiveness, Sustainability, Threshold limits, Organizational, Restoration, Enhancement and Disaster risk reduction) strategy to assess the added functionality of the MSN processes, systems and standards. The RESTORED strategies are evaluated using a suite of Decision Support System (DSS) tools to illustrate how we can meet the negative impacts of climate change to slow down if not arrest resource depletion, biodiversity loss and degradation of ecosystem goods and services. Combining various versions of the FISH BE model, CoastPLAN, Reef GAME and CTI-VA, we elucidate how the integrated enlarged network MPA- which incorporates adjustments derived from the use of the RESTORED strategies for actions- can result in synergistic effects. These tools are helpful in various applications such as: i) targeting social and ecological objectives; ii) evaluating the processes, systems and standards of threshold actions; iii) tracking performance progress and governance levels; and iv) effectiveness in achieving results and impacts. The MSN case shares the rich experiences of how good coastal theories are enhanced by the engagement of a community of practitioners (CoP), including scientists and stakeholders. The costs effectiveness of these measures is shown by an increased cost benefit ratios *vis-a-vis* sole management, and accelerated time in achieving conservation objectives. Participatory targeting and coordinated planning by engaging and motivating the stakeholders, as assisted by informed DSS communication tools help build capacity, constituency and advocacy for the CTI goals. In order to make the CTI actions happen using this arsenal of tools, knowledge and CoP is an imperative.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1630, Sebel Bluewater

Challenges in developing large marine protected area: Danajon Bank, Philippines

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Marine protected areas (MPAs) have become an important tool in coral reef management in the Philippines. Contributing to their proliferation is the local governments' devolved mandate to manage their coastal and marine waters. MPAs are a significant strategy to improve marine protection by restoring fishery resources. However, the majority of Philippine MPAs are relatively small in size and have inadequately met conservation objectives. To address common issues and shared benefits, an effort to identify and protect a large and key marine ecoregions is being carried out in Danajon Bank, which is an important biodiversity area and the only double barrier reef in the country. This unique ecosystem is under the jurisdiction of more than 12 local government units. Establishing a large MPA under a collaborative ecosystem-based management approach is crucial to achieve ecosystem protection goals and manage fishery resources. This paper documents the current efforts of the Danajon Bank Project to protect Danajon double barrier reef located off the coasts of the islands of Bohol, Cebu, and Leyte in Central Philippines. The paper also documents several challenges and opportunities. These include: habitat mapping, socio-economic profiling, institutional arrangement and coordination, coastal law enforcement, MPA management planning, and stakeholder support and participation.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1755, Sebel Bluewater

Developing resilient marine protected area networks across seascapes in Fiji

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Despite recent advances in our understanding of climate change impacts on coral reef ecosystems, applications of this knowledge to inform conservation planning and management strategies remain rare. We discuss how site-level indices of reef resilience have been incorporated in: (1) adaptive management of an existing community-based marine protected area (MPA) network in Kubulau District, Fiji; and (2) the expansion of the network across 4 adjacent districts. Reef resilience surveys were conducted at 197 sites between March 2010 -

2011. Factors likely to confer resilience to climate-induced bleaching events, including biomass and functional diversity of herbivorous fishes, coral community susceptibility to bleaching and potential for post-disturbance recovery, were assessed for each site, and used to identify critical areas for inclusion in MPA networks. Although resilience was not considered during the initial design of the Kubulau MPA network, some of the most resilient reefs in the region are protected within these MPAs due to fortuitous design and enhanced resilience through recovery of herbivore populations within MPAs. In response to new information on the degree to which reef resilience might be improved through spatial management, Kubulau communities increased the size of several existing MPAs and proposed one new MPA. The design of new MPA networks in 4 adjacent districts was informed by reef resilience from the outset, in addition to considering habitat representation and socioeconomic priorities. We also discuss the potential utility of spatially modelling factors which confer resistance and recovery potential to enable development of explicit targets for resilience using decision-support software.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1645, Sebel Bluewater

Redefining MPA planning processes in the CTI

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Social ecological research around the world demonstrates that marine protected areas (MPAs) are more likely to succeed when based on participatory implementation and equitable benefit distribution. Ambitious MPA networks, which currently tend to overlook these planning elements, run the risk of local resistance leading to unintended negative impacts for society and ecosystems. Drawing from extensive quantitative and qualitative data, examination of successes and failures in the Philippines and Indonesia demonstrates that inclusion of varied stakeholder worldviews and expectations is essential to MPA success. This examination will highlight the imperative of participatory and equitable benefit distribution for the realization of MPA ecological goals. Creating such planning processes will require a re-organization of current planning and implementation processes in many contexts. The talk will examine barriers to planning reform. Possible barriers include biases intrinsic to influential scientific-conservationist epistemic communities and a poor understanding of feedbacks between social and ecological systems. Practical ideas for planning reforms, including learning networks involving scientists, policy makers, and resources, are summarized.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1200, Sebel Bluewater

Periodic closures: securing fisheries for the future?

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Temporary marine area closures have been practiced traditionally throughout the Coral Triangle. The use of traditional closures has declined, but contemporary initiatives to establish networks of community-based marine managed areas promote their reinvention as small reserves that may be subject to periodic harvesting. Periodically harvested reserves are touted as being a successful traditionally-based measure for marine management. There is, however, scarse evidence that the strategy will lead to sustainable management of fishing grounds and the range of taxa exploited by small scale and subsistence fisheries. Catch and effort data from 5 periodically harvested reserves in Solomon Islands indicated that in some cases, a majority of fishing effort from continuously open fishing grounds redistributed to newly opened areas. However, minimal effort redistributed to newly opened areas that were considered as sub-optimal fishing grounds or fishing rights to that area extended to only a small proportion of the community. In the most intensely fished opened area, fishing effort commenced at levels significantly higher than observed in continuously fished grounds. Gleaning and line fishing effort decreased significantly towards the end of the opening period, tracking a decline in catch rates. Populations of several taxa were appreciably depleted by harvests. We find that alleviating fishing pressure on an area during times of closure allows for stock replenishment; however, moderate, heavy or destructive harvesting during openings can exceed stock recovery of some taxa. Our findings illustrate some critical fisheries management considerations for periodically harvested reserves employed throughout the Coral Triangle.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1545, Sebel Bluewater

Predicting management costs of protected areas in the Coral Triangle

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Marine Protected Areas (MPAs) are set to be one of the main mechanisms used to protect the Coral Triangle from increasing human impacts. If MPAs are to be effective they must be adequately funded, but as yet there is no reliable method available to decide the correct level of funding for individual MPAs to achieve specific objectives. Here, we outline a project which develops the tools to indicate the correct level of funding for a MPA with defined objectives and specific biophysical and governance characteristics. The project will take both a bottom-up and top-down approach. The bottom-up approach will gather data on the current costs of each management activity in individual MPAs and also asks managers what level of funding would actually be required for each activity to achieve all objectives. The top-down approach will develop predictive models of management costs based on predictors including habitat type, location, configuration, and management approach. The project will bring together a wide range of stakeholders in order to generate justifiable estimates of minimum and ideal levels of MPA funding. Furthermore, it will benefit conservation planning by integrating management costs into prioritisation methods and will allow estimates of overall costs of MPAs in the region.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1245, Sebel Bluewater

Biophysical principles for designing resilient MPA networks with multiple objectives

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Fisheries are one of the most important marine ecosystem services benefiting the people and communities of the Coral Triangle. Overfishing and loss of key habitats and stocks is severely undermining the long-term sustainability and food security of the region. Marine protected area networks, comprising different levels of protection, can, if well designed and effectively implemented, play a significant role in achieving sustainable use of coral reef and associated resources. For the first time, biophysical design principles for marine protected area networks have been developed to help address the 3 objectives of sustaining fisheries, conserving biodiversity and building climate change resilience. These principles refer to the range of types of marine protected areas. They provide specific recommendations about the overall amount of protection needed (ideally, 30%, or at least 20%, in no-take areas and more in other kinds of protection) and the overall size of multiple-use managed areas (as large as possible to include as much of the ecosystem as possible). The biophysical principles also have recommendations about individual marine protected areas within the network regarding: i) their size (at least 40 ha for no-take areas; ii) various suggestions for other kinds of protection); iii) spacing (1-20 km apart); iv) location (representing all habitats, especially critical habitats, avoiding threats, up-current, special, unique and resilient sites); v) frequency (at least 3 replicates); vi) shape (more circular or square); vii)duration (>20 yrs but best permanent); and viii) boundaries (both within habitats and at habitat edges). The principles are also prioritized to increase the likelihood of successful outcomes.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1715, Sebel Bluewater

Designing community-based marine protected areas to achieve multiple objectives

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Community-based approaches are the most effective method for establishing marine protected areas (MPAs) in many places in the world, including the Coral Triangle. To improve their ability to achieve multiple objectives (e.g., fisheries management, biodiversity conservation, climate change resilience), we must address the mismatch between existing ecological principles for MPA network design and the realities of community-based MPAs. Most existing design principles call for larger no-take MPAs (tens of square kilometers), spaced at moderate distances. However, these rules of thumb are impractical in many places where the focus is on small (0.1-10 square kilometers) community-managed MPAs and there are concerns regarding potential negative impacts of MPAs on community livelihoods.

Maximizing the ecological benefits of community-based MPAs requires that design principles for MPA networks be refined to acknowledge the opportunities and constraints of community-based management and their potential effectiveness at meeting different objectives. We present recently developed design principles for size, spacing and types of MPAs to achieve fisheries, biodiversity and climate change objectives across a range of scales. We reviewed the best available information on the movement patterns and life history of reef fishes and coastal pelagic fishes in the Coral Triangle, including recent advances in our understanding of larval connectivity, and used this information to develop rules of thumb for community-based MPA network design. Results will be developed into products to communicate key recommendations to communities and local decision-makers to assist them in designing MPA networks that are more effective in meeting their objectives.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1500, Sebel Bluewater

Marine protected areas: understanding social impacts through time in North Sulawesi, Indonesia

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Marine protected areas (MPAs) are commonly employed in coral reef systems throughout the world as a principal tool to mitigate degradation and biodiversity loss. However, the efficacy of MPAs is highly variable. A significant factor impeding their success is a lack of consideration and understanding of the dynamics of associated human systems. Ultimately the purpose of MPAs is to restrict human activity, thus acceptance of and adherence to management by stakeholders is integral to achieving biological gains and sustainable outcomes, particularly in developing countries where resources for enforcement are often limited. Stakeholders' support for MPAs largely rests on of the relative costs and benefits to them of the intervention, as well as their beliefs and attitudes towards the marine environment and natural resource use. These issues are critical to MPA planning and management, yet remain poorly understood. To address this gap, we are investigating the long-term impacts of MPAs on human well-being and stakeholders' perceptions of marine resource use in North Sulawesi, Indonesia. The implementation process for these MPAs was initiated in 1997 and spanned 6 years, after which external support was withdrawn. Using social data from pre-, mid- and post- implementation, as well as results from current surveys, we are comparing how several dimensions of human well-being have changed over time in project and control communities. We expect that this research will inform future management decisions by elucidating the contextual and management factors that drive negative and positive social impacts of MPAs, and that foster a conservation ethos.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1145, Sebel Bluewater

Corals, canyons & corridors: integrating deep-sea habitats into Indonesia's MPAs

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Indonesia is positioned at the nexus of two oceans. Its diverse deep-sea habitats include migration corridors, seamounts, canyons, trenches and upwelling zones that are of regional importance within the Indo-Pacific, yet remain poorly understood. From 1998-2011 visual and acoustic surveys and research were conducted on blue whales, sperm whales and other oceanic cetaceans. Outcomes have been instrumental to a) identify critical deep-sea habitats of large cetaceans and other migratory megafauna, and b) support MPA management in Indonesia. The Lesser Sunda ecoregion (Bali to Timor Leste) GIS mapping project categorized 13 distinct deep-sea habitat types. Ecological and human use characteristics were evaluated for all identified sites. Due to the extreme depth gradients, numerous seamounts and persistent pelagic habitats were located near-shore. There is a clear opportunity to improve the protective management for these deep-sea yet near-shore habitats. Simultaneously, technological advances have allowed a rapid expansion of pelagic fisheries and a boom in oil and gas activities in deep waters. Regional shipping is estimated to increase significantly, especially along major shipping lanes which overlap with migration corridors. Currently, deep-sea habitats are vastly under-represented in policy development and MPA networks throughout the Coral Triangle. This marine conservation gap is slowly being addressed. The design of the Raja Ampat, Savu Sea and Kimbe Bay MPAs specifically included canyons, corridors and seamounts. Conservation measures for associated oceanic megafauna species are being implemented. This new development may be relevant to other archipelagic nations such as the Philippines, Papua New Guinea, and the Solomon Islands.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1215, Sebel Bluewater

Food security amidst climate change through MPAs

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Small islands like Lubang in the Philippines are highly vulnerable to climate change impacts since communities heavily rely on marine resources for their livelihoods and daily sustenance. Conservation, management and climate change adaptation planning in this island group of 2 adjoining municipalities have recently been mainstreamed to management approaches for food security, resource rehabilitation and conservation, and climate resilience. Perception mapping exercises of local knowledge on marine resources, their uses and threats, and coastal resource assessments coupled with larval studies and dispersal simulations identified key marine areas around the island for protection using climate-smart principles. These fed into massive information and education campaigns for local communities and capacity building for local enforcement volunteers who protect their coastal areas from poachers. This highly participatory process resulted in the establishment of 14,485 hectares of MPA system, the largest in the Verde Island Passage network of MPAs. Expectations on the benefits of this MPA system are high and regular resource monitoring is being set up to track the benefits and feed into a climate adaptive management cycle. Key lessons on MPA establishment and management in Lubang Islands may serve as a model for other areas in the country where MPAs are still limited in scale.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1255, Sebel Bluewater

The importance and challenges of an MPA network in Bali

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We describe the importance and challenges of implementing an MPA network in conserving Bali's marine biodiversity. The Indonesian government plans to establish 20 million ha of MPAs by 2020; Bali targets approximately 60,000 ha. The island has approximately 8 existing and proposed MPAs. Bali MPA network was established to effectively manage these MPAs. The Bali MPA network includes 3 sustainability elements (ecology, socio-cultural and governance) to achieve green economy. Based on 2010 stakeholder workshops and 2011 rapid assessment, the MPAs within the network were chosen because of the ecological connectivity between coral reefs, reef fish, sea grasses, mangroves and marine megafauna. The network respects Bali's indigenous wisdoms of Tri Hita Karana (traditional sustainability framework), Nyegara-Gunung (traditional reef-to-ridges concept) and Sad Kertih (six prosperity elements). The network attempts to foster effective collaboration among MPA managers, e.g., through capacity building and sustainable financing. The Bali government is committed to the island-wide MPA network. The network is expected to cover three MPAs in Buleleng, a proposed MPA in Karangasem, a declared MPA in Nusa Penida (Klungkung), a proposed MPA in Badung, a proposed MPA in Jembrana and the existing Bali Barat National Park. Due to readiness in ecological and governance connectivity, the first development stage focuses on three northern MPAs in Buleleng. Technical challenges in the eastern and southern MPAs mean they will be targeted in the second stage. We recommend that MPA networks are used to manage geographically and ecologically connected MPAs, taking into account local context and human resources capacity enhancement.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1750, Sebel Bluewater

A new paradigm for Marine Protected Area management in Indonesia

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Under national policies on fisheries and fisheries resource conservation, Indonesia is now entering a new paradigm for Marine Protected Area (MPA) planning and management. Conservation programs in the past were based on centralized policies and strict limitations on resource utilization. Under the gGovernment of Indonesia's new policies, marine and aquatic resource conservation is being supported by 3 central policy pillars; preservation, conservation, and utilization. Planning and management of MPAs throughout Indonesia is now able to be initiated by local governments through decentralized natural resource management policies. Zoning of MPAs is also shifting to multi-purpose zones by providing places for sustainable fisheries and tourism activities. Through this approach, the number and coverage of MPAs is increasing rapidly with more than 15 million ha of MPAs declared. Two-thirds of the MPAs are locally-based, being initiated, established and governed through district regulations. This heralds a significant contribution to the

Government of Indonesia's commitment to establish 20 million ha of MPAs by 2020.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1530, Sebel Bluewater

Networks of marine reserves as fisheries management and conservation tools on Philippine coral reefs

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For almost 40 years no-take marine reserves have been a key tool for the management of coral reef fisheries and in the conservation of Philippine coral reefs. During this period, methods of community-based establishment and management of individual marine reserves have been refined, recovery rates of fish and coral populations and communities in reserves have been quantified, and the effects of spillover from reserves of post-settlement reef fish on local fish yields have been documented. In the past decade, research and management emphasis has shifted toward the establishment and functioning of networks of marine reserves. More than 1000 marine reserves have been established in the Philippines, most of these in the south of the country. We are currently employing larval dispersal modeling and larval tracking techniques in areas with existing reserve networks to quantify the degrees to which larvae of coral reef fish self-recruit to individual marine reserves, are exchanged among reserves, and are exported from reserves to fished areas. The latter process of export, known as recruitment subsidy, is critical to the success of networks of reserves as fisheries management tools. Preliminary results suggest that large numbers of even small individual reserves (< 0.5 km^2) protecting relatively modest percentages of coral reef area (~10-15%) can make significant contributions to the management and conservation of coral reefs in this region.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1130, Sebel Bluewater

Matching governance to context: institutional strategies for networking CTI MPAs

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Realizing the Coral Triangle Initiative goal for establishing an MPA system will require managing MPAs across a region that is highly diverse in its socio-ecological context and existing institutional arrangements for coral reef management. Since these contextual variables moderate the ability of MPA arrangements to achieve their goals, this research analyzed the experience of 60 coral reef management projects to understand which institutional arrangements were best suited to varying socio-ecological contexts. Using mixed quantitative-qualitative methods we identified 5 approaches for establishing and supporting MPAs used in the region: centrally-managed parks that emphasize tourism and conservation; locally-managed sanctuaries that emphasize sustainable use and community empowerment; multi-partner, area-based initiatives that emphasize protecting outstanding ecological resources by facilitating livelihood development; volunteer-oriented initiatives that emphasize environmental stewardship through restoration and livelihooddevelopment activities; and, adaptive management initiatives aimed at maintaining stewardship by providing comparative science-based feedback across sites. For the main approaches to MPA management, we found that the type of institutional arrangement used was influenced by ecological condition, national government policies, and resource dependence. We also identified contextual characteristics that can be considered prerequisites to the perceived success of the main approaches to MPA management, and the comparative strengths and weaknesses of each approach for achieving different goals, from ecological conservation to sustainable use. These results allow us to recommend a series of actions that can be taken to improve the ability of each approach to achieve a balanced set of MPA goals that includes equity, ecological sufficiency, and institutional sustainability.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1730, Sebel Bluewater

Fishery and ecotourism along a marine park: compatible or conflicting?

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The classic aim of balance between conservation and capture fisheries is a common yet an elusive one. Donsol is a coastal town in the Philippines considered as the 'whale shark capital of the world', which also supports a sardine capture fishery. A portion of its municipal waters has been declared a marine conservation park while more than half of it is still an open fishing ground. Fishery assessment of sardines, predominantly *Dussumieria acuta*, showed high exploitation rates. Bottom set and drift gillnets are the major gears for sustenance fishing. Commercial fishing vessels operating purse seine were also reported in the area. From a vulnerability assessment study, whale shark or 'Butanding' interaction officers (BIO) perceived coastal sea warming, early monsoon occurrence, and rising level of coastal seawaters, which they attribute to result in the decline of whale shark sighting frequency. BIOs are government-accredited personnel who accompany and guide tourists who, for a minimal fee, can interact briefly and safely with the 'largest fish in the world'. Whale shark and sardines could be swimming along the same path because they both feed on zoopankton. Small-scale fishers said they intentionally avoid whale sharks while fishing because their nets and boats will surely be destroyed when the large fish swim at them. But they disclosed that the large commercial fishing vessels can potentially hurt a whale shark when it is hit by them. The local government-assisted by an international NGO-has been pursuing measures to protect the largest fish and the fishers. Is there a way toward a balance?

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1745, Sebel Bluewater

Contrasting effects of marine reserves and habitat change on reef fishes in the Coral Triangle

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No-take marine reserve networks are being widely implemented throughout the coral triangle as a tool to promote sustainable fishing and protect biodiversity. Increases in the abundance and biomass of exploited species within reserve boundaries have been demonstrated. However, the ability of reserves to protect the majority of species in areas with substantial habitat degradation is less clear. To date, there have been relatively few long-term studies of no-take areas before and after reserves have been implemented. Here, we report on decadal changes in fish communities in 4 small coastal reserves and 4 reefs open to fishing in Kimbe Bay, Papua New Guinea. Reef fish densities and benthic cover were monitored for 3 years before (1997-1999) and 12 years after (2000-2011) reserves were implemented. Substantial reserve effects were recorded for several reef fishes, primarily exploited Surgeonfish species. These effects gradually accumulated, with some evidence that the effect size may have peaked due to only partial compliance. For most small, coral-associated fishes, the long-term dynamics, at both reserves and fished reefs, reflect cycles of decline and recovery in branching coral cover. While fish biodiversity recovered from a low point in 2002, it has never returned to pre-1997 levels. There is evidence of long-term habitat degradation, with increasing macroalgae and sediment cover, which may hinder the ability of reefs to recover after periods of decline. Our results support the view that no-take areas are necessary for coral reef conservation but must be supplemented with effective measures to reduce extrinsic impacts on coral health.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1700, Sebel Bluewater

Top-down bottom-up approach to MPA capacity building in Indonesia

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Capacity building and skills and knowledge transfer into the field to improve MPA management effectiveness continuously remains a challenge. In part, the challenge has been the fragmented, institutional structure of MPAs, with policy and initiatives driven from the top-down; while daily management of MPAs is driven from the bottom-up, trying to meet the needs and demands of local communities and interests. Building off a MPA capacity building model developed for 12 MPAs in the Bird's Head Seascape (BHS) of Papua, Indonesia, we found the need to synchronize and strengthen capacity at both levels. Through a partnership between CI, TNC, WWF and NOAA, we identified priority resource management issues and associated skills and

knowledge to address these issues. After 3 years of using this as the basis for building capacity for the BHS MPAs, a hybrid of this model is being applied to the Ministry of Marine Affairs and Fisheries at the national level. National and district level resource managers are receiving training on the issues, skills and knowledge required to not only manage MPAs at the local level, but also set policy and initiatives at the national level that support improved management effectiveness of MPAs throughout Indonesia. The question remains, are we seeing improved cooperation and synchronized decision-making for MPAs, and most of all, improved MPA management effectiveness? If so, then how do we institutionalize this model to serve the expanding needs of MPAs in Indonesia, and other CTI countries.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1230, Sebel Bluewater

New paradigm on establishing MPA in Indonesia: a case study from Nusa Penida MPA

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Sustainable management of common resources such as fisheries is one of the most vexing problems facing conservation. Marine protected areas (MPAs) have become a widely adopted tool for the management of marine commons, with mixed success. A key decision surrounding MPAs is exactly who manages them and how. For now, MPAs in Indonesia are managed by 2 regimes: government and communities. Unfortunately, in management actions within these MPAs, there are tensions between government and communities, especially inside national parks that are managed by the central government. Since 1998, however, civil society and local communities have grown in power and have developed more autonomy. The new political situation has given wide opportunities for local governments as well as local people to be active in establishing and managing MPAs. Conflict arises because the management approaches embraced by local communities often differ from the management approaches favored by the national government. A new approach -collaborative management, in which government and communities work hand in hand to establish and manage MPAs - may offer a way out of this conflict. The new approach positions government and communities to share the responsibility, authority and benefit of establishing and managing MPAs. Collaborative management balances community-based decision making with top-down government authority.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1250, Sebel Bluewater

Marine protected areas in the Coral Triangle: issues and options

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The 6 Coral Triangle countries of Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Island and Timor Leste have evolving systems of marine protected areas (MPAs) at the national and local levels. More than 1500 MPAs have been established within these countries over the last 40 years under legal mandates that range from local village level traditional law to national legal frameworks that mandate the protection of large areas as MPAs. Protection has primarily focused on critical marine habitats and ecosystems with a strong interest in maintaining and improving the status of near-shore fisheries that are a primary food and economic resource in the region. We review the status of MPAs in the 6 countries with regard to coverage of critical habitat, areas under effective management, and issues that need to be resolved to improve the implementation of MPAs as a marine conservation and resource management strategy. Options for resolving key issues in scaling up the existing system of MPAs to a network of MPAs that are more ecologically linked and integrated with fisheries management are discussed. Finally, we note that even though MPAs have become an accepted method of addressing marine conservation and fisheries issues, there is a need to think and plan in an integrated and broad manner which leads to ecosystem-based management regimes, within which MPAs are a key strategy.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1115, Sebel Bluewater

Long-term investments by an NGO for Marine Protected Area management support: is it worth it?

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Wakatobi National Park in Indonesia was declared a Marine National Park in 1997. Invited by the National Forestry Ministry, WWF and TNC worked at the National Park since

2002 to improve management effectiveness. Three strategies were developed and implemented: management planning & design, monitoring & surveillance for adaptive management, and Community outreach and empowerment for collaborative management. Declaration of Wakatobi as new Regency in 2003 had implications for the zonation and management plan revisions. In 2007 the new zoning plan was endorsed following a long process of many public consultation meetings that incorporated data from biodiversity monitoring, perception monitoring and surveillance activities. Subsequently, the new management plan was endorsed in June 2008.The monitoring program shows how the ecosystem has changed, and that compliance of fishers with regulations has improved. Perception monitoring shows that more park inhabitants understand and support the park's purpose, and are more involved in management. Also, management skills and field presence of the authority improved, and the program increased media coverage on the park. Management costs incurred by the NGOs and park authority are well within the range of published costs for other MPAs, and because results were measurable and significant, we conclude that NGO investment in protected area management paid off.

17B Marine Protected Areas & networks in the Coral Triangle
Tuesday 10 July, 1515, Sebel Bluewater

17C Regional-scale design & local-scale actions for marine conservation conservation

Socioeconomic connectivities in the Coral Triangle

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The estimated annual value of the coral reefs, mangroves, and its associated habitats in the Coral Triangle (CT) amounts to US$2.3 billion. The CT provides a multi-billion US dollar tuna industry, US$1 billion annual trade in live reef food fish, primarily traded to Hong Kong and South China, and over US$100 million annual trade in live reef aquarium fish and other ornamentals; industries that directly support one-third of the 350 million people in the region for their income, livelihoods, and food. The CT is a net fish exporter to the global trade, with a large proportion of fish exported to Japan and USA. The region, which covers only 1.6% of the world's ocean area, contains one-third of the world's coral reefs. Remarkably, it is also a major source of live coral exports contributing up to 80% of the world's coral export. In this work, we analyze and describe the macro-micro socioeconomic connectivity of the countries in the CT and the connectivity of the CT as a region to the other parts of the world. This study focuses on the dynamics of the live-reef fish food trade, coral trade, regional policies and international trade treaties, and flow of fishing pressure in the region. We discuss the potential to harmonize the CT's social and economic inequities at a a local and global scale by using informative decision support tools.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1200, Sebel Bluewater

Scaling up the collaborative environmental monitoring plan in Semporna, Sabah

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The Semporna Priority Conservation Area (PCA), within the Sulu-Sulawesi Marine Ecoregion (SSME), displays some of the highest marine biodiversity in the world. Within the Semporna waters, a few government bodies are responsible for different islands. For example, Tun Sakaran Park was gazetted under the management of Sabah Parks. Sipadan Islands, and its surrounding waters, are under the protection of Majlis Keselamatan Negara. Omadal Island was managed by the Department of Fisheries for seaweed farming. Mabul Island is managed by the tourism operators due to its popular neighboring island, Sipadan Island. Mabul Island has 26 hectare of land (Aw et al, 2006), houses 2500 residents that rely on the fisheries and more than 15 resorts and dive lodges. Reefcheck surveys, community-based seagrass surveys, seawater quality monitoring and groundwater analyses have all been conducted on Mabul. The environmental condition of the Mabul Island is such that it is a source of pollution likely to spread to other islands within Semporna PCA. Collaborative environmental monitoring was identified as the only way to reverse the human impact and was started in Mabul Island. This plan should be spread to other islands in the future in order to protect the marine environment from pollution. We provide a site-specific study on ways of scaling up the local action plan in order to make it significant and to contribute to regional planning within the Coral Triangle Initiative.

17C Regional-scale design & local-scale actions for marine conservation
P182

Science, scale, development and governance in Marine Protected Area planning: lessons from Timor Leste

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Consideration of socio-economic and cultural systems, as well as biophysical systems, is increasingly being recognized as critical for effective, spatial marine conservation planning programs. Effective governance (i.e., enabling institutions, arrangements, legislation, policies and processes) is also essential for implementation, particularly in large-scale or regional conservation planning programs. These new approaches include incorporating socio-economic and cultural factors into systematic protected area planning, implementing both 'bottom-up' community and 'top-down' continental conservation models, in order to find ways of integrating across scales and between Indigenous knowledge and conservation science, and to support conservation-based economies. As a newly-established nation and LDC, Timor Leste is among the 20 poorest countries in the world, with some of highest levels of population growth, infant mortality, malnutrition, unemployment, illiteracy and food insecurity in the South East Asia. With 94% of coastal communities highly dependent on coastal resources, marine protected area (MPA) planning must address both biodiversity conservation and also, human health and sustainable economic development. The Government of Timor Leste is committed to establishing MPAs and since 2006 (with support from international partners), has developed policies and also, multi-scale programs to implement a system of MPAs, including network design and implementing Timor Leste's first MPA, the Nino Konis Santana Marine Park. We outline and critically review the past and current range of MPA science and planning programs in Timor Leste (including the Northern Territory, UNDP-PoWPA, FAO, USAID-CTSP, ADB-CTI, AusAID-SEWPaC, UNESCO) and significantly, explore the critical issues of science, governance, human development in multi-scale MPA planning, and the implementation of individual MPAs.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1115, Sebel Bluewater

Breaching regional-scale initiatives with local-scale actions: marine protected area networking in the Philippines

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In the Philippines, existing conservation efforts for marine protected areas (MPAs) are increasingly scaling up to networks of MPAs within a common ecosystem. These are aimed to address primary issues of degradation of marine and coastal ecosystems and illegal fishing activities, and contribute to regional scale initiatives in the Coral Triangle. The Visayan Seas marine ecoregion is considered to have the highest exploitation levels in the Philippines. To address the growing need for integrated marine conservation and fisheries governance within this ecoregion, multiple local governments are setting up resilient networks of MPAs. Southern Cebu is an inter-municipal partnership that is working at integrating over-arching principles of MPA network design in order to maximize biological/social benefits. Northern Cebu municipalities are consolidating coordination efforts for MPA network enforcement while strengthening integrated coastal management. Siquijor is the first Philippine province to have committed to a provincial MPA network and management plan that integrates resilience science into MPA management. The Danajon Bank Marine Park is an initiative towards large-scale collaboration of municipalities of a double barrier reef. Challenges and lessons inMPA networks are increasing, including stakeholder participation, institutional arrangements, resource use and access, and sustainable financing.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1230, Sebel Bluewater

Status of fisheries and aquaculture in the CT6

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The Coral Triangle Initiative for Coral Reefs, Fisheries, and Food security aims to achieve

sustainable management of marine and coastal resources for current and future generations. Information on production, fishing effort, fish stocks, exploitation status, and trade were obtained from the CTAtlas, global databases, in-country statistics, reports, and published literature to provide a spatially-explicit mosaic of the state of fisheries and mariculture in the coral triangle countries. In 2009, the 6.2 million fishers of the coral triangle countries caught a total of 8.7 million tons of marine fish and invertebrates and cultured 5.1 million tons of marine products, contributing 12% of global fish supply. The contribution of the CT6 fisheries to global fish supply has been steadily increasing from 2.4% in 1950 to 12.4% in 2009. Major catches in the CT6 are from the family Scombridae, Carangidae, and Clupeidae. Also in 2009, the CT6 accounted for 30% of global production of tuna, bonitos, and billfishes, excluding catches by offshore foreign vessels in the Pacific Islands. The unique diversity of marine life in the region is increasingly threatened as documented by the rapid increase in catches of turtles, corals, and shells with the CT6 accounting for 97%, 79%, and 55% of global production for each group, respectively. Although many of the nearshore fishing grounds in the CT6 are heavily exploited, increasing production in all 6 countries and fish stock assessments reveal pockets of less exploited fisheries which can be targeted for priority and early fisheries management.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1035, Sebel Bluewater

Scaling-up marine protected areas in the Philippines

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Marine protected areas (MPAs) are the most extensively implemented fisheries management and conservation tool in the Philippines. Most MPAs have been established and managed by communities together with local governments in community-based and co-management schemes. These methods have proven successful in terms of gaining community acceptance and achieving local-scale fisheries and conservation objectives. However, the effective contribution of these MPAs to ecological networks of connected MPAs is variable since most individual MPAs were not planned to form networks. Nevertheless, there is growing support for the development of MPAs within the national integrated coastal management framework, which supports the "scaling-up" of MPAs to form networks. Scaling-up in the Philippine context is achieved by forging inter-institutional collaboration among neighbouring local governments, with the assistance of other institutions such as non-government organisations, academe, government agencies, donor-assisted projects, and provincial governments. This paper describes the approaches used to scale up MPAs to form networks in the Philippines and the remaining challenges in establishing and governing MPAs that are institutionally and ecologically connected.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1030, Sebel Bluewater

Blue carbon:reducing climate change impacts in the Coral Triangle

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Coral Triangle coastal ecosystems support multi-billion dollar tuna, fishing and tourism industries and over 100 million people rely directly on its coastal resources for their food and livelihoods. Coastal ecosystems, in particular seagrasses, mangroves, and saltmarshes, however, are also known as blue carbon sinks because they can transfer and store carbon in their sediments at rates far greater than those of rainforests, potentially for centuries. The Coral Triangle contains the majority of the world's mangroves and seagrass and there is growing interest in the role of these ecosystems in climate change mitigation and adaptation strategies across the region. Conserving these coastal ecosystems not only removes greenhouse gases from the atmosphere, but it is an immediate and cost effective way to help coastal communities adapt to climate change. Understanding and acknowledging of the role of blue carbon in climate change mitigation may promote the development of a market-based payment for ecosystem services which could support the sustainable management of these coastal ecosystems. WWF has been working in the Coral Triangle for over 20 years and aims to protect the resilience and extraordinary natural wealth of this region through collaboratively managed practices across political and cultural boundaries in order to create economic opportunities for the people who live here and depend on natural resources for their livelihoods. This paper aims to stimulate discussion and debate as to how to promote and utilise healthy coastal ecosystems and the invaluable benefits they provide to support a

sustainable and more climate-resilient future for Coral Triangle communities.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1215, Sebel Bluewater

The Micronesia challenge: a regional commitment built on local stewardship

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Due to geographic isolation and proximity to the Coral Triangle, Micronesia's islands contain highly diverse marine and terrestrial resources. Yet the features that make these islands exceptional also make them especially vulnerable to environmental threats such as deforestation, unsustainable fishing practices, invasive species, and climate change. In 2006, to ensure a healthy future for their island communities through sustainable management of their natural resources, the Chief Executives of the Federated States of Micronesia, Republic of the Marshall Islands, Republic of Palau, U.S. Territory of Guam and the U.S. Commonwealth of the Northern Mariana Islands launched the Micronesia Challenge (MC) - the first large-scale regional conservation commitment. With a goal to effectively conserve at least 30% of near-shore marine resources and 20%of terrestrial resources across Micronesia by 2020, the MC encompasses 6.7 million km^2 of ocean, and will help protect 4% of the global total reef area and over 480 coral species. Although the initiative built on decades of foundational work by Micronesian communities and organizations to raise awareness, strengthen capacity, and implement conservation activities in their home islands, it resulted from the realization that Micronesians must work together at the regional level to confront global threats in a rapidly changing world. In the past 5 years, the MC has provided an effective regional framework for coordination, capacity-building, marketing and sustainable finance. As a result, this has leveraged greater resources directed toward national, state, municipal, and community level policy, planning, establishment/strengthening of protected areas, implementation of management actions, and monitoring and measuring progress.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1245, Sebel Bluewater

Explicitly incorporating socioeconomic criteria and data into marine spatial planning

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Many Indonesian marine protected areas (MPAs) often have low community compliance to governing regulations. Low compliance is thought to result from a lack of perceived benefits from MPAs, poor community engagement in the planning process, and perceptions that managers ‘care more about fish than people'. Land and sea tenure are strong in Papuan culture and provide a unique opportunity to engage with, and empower, local communities to manage large MPAs. We demonstrate how socioeconomic factors, including tenure, were incorporated into the planning process and contributed to the final design of multiple-use zoning plans for 2 MPAs in Raja Ampat, West Papua, Indonesia. Key datasets that were used included multi-year surveys of community perceptions about MPAs, patterns of resource use and extensive community mapping of important fishing grounds and conservation features. Socioeconomic data were combined with biological data and analyzed using the decision-support software tool 'Marxan with Zones' to help identify and prioritize areas for inclusion in sustainable community fisheries zones and no-take zones. In addition, traditional systems of management ('sasi') were identified and revived, with zoning regulations designed to ensure community declared sasi areas were incorporated into the zoning design and thus supported by Indonesian law. By explicitly including socioeconomic criteria and data into zoning, the final zoning plans will better reflect the communities’ development aspirations as well support their long-term food security and livelihoods needs, and hopefully lead to long-term compliance.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1130, Sebel Bluewater

Moving between scales to successfully achieve marine conservation goals

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Allocation of resources for marine management across space would ideally integrate knowledge of the relevant socio-ecological system from a regional (e.g. broad patterns in biodiversity, ecological processes) and local (e.g. specific values and costs to individual communities) perspective. However, there are multiple barriers to incorporating both perspectives in decision-making, including institutional priorities and limitations to resource governance. Consequently, challenges persist in either scaling up local conservation actions to incorporate regional insight, or scaling down regional systematic plans to a scale that effectively guides local action. To better understand the processes and characteristics of the social-ecological systems that facilitate scaling conservation initiatives up and down, we reviewed multiple conservation initiatives that have done so successfully. We present the strategies used by these initiatives to work across multiple scales, and the challenges encountered and lessons learned. Based on these case studies, we developed an operational model for conservation initiatives working across different scales. Our findings are timely, as local conservation initiatives start to adapt to regional and global threats (e.g. impacts from climate change) and the importance of translating regional conservation assessments to conservation actions on the ground is increasingly emphasized.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1145, Sebel Bluewater

Seascape connectivity and reserve performance: effects across the western Pacific

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The degree to which populations and habitats are connected has important consequences for their persistence, productivity, and resilience. Coral reef fish depend on reefs, but also utilise a variety of other habitats during their lifecycles. Mangrove and seagrass habitats are particularly important as juvenile nurseries and foraging locations, and their position relative to reefs can affect the demography of reef fish populations and the composition of reefal assemblages. Enhancing this connectivity is now a common consideration for conservation, yet limited information is available on its potential role for reserve design. We used an exploratory seascape approach to examine the influence of seascape connectivity on reserve performance by investigating its affect on fish assemblages in the back-reef seascapes (i.e., with coral reef, mangrove and seagrass) of 3 western Pacific locations: the Solomon Islands, Great Barrier Reef and Moreton Bay (Queensland). We surveyed fish on fringing reefs and adjacent mangroves at multiple levels of spatial connectivity, in both no-take reserves and areas open to fishing. Protected reefs close to mangroves typically supported more snapper (Lutjanidae), sweetlip (Haemulidae), bream (Sparidae), rabbitfish (Siganidae) and harvested fish than similar unprotected locations, or other more isolated reserve locations, but the magnitude of effect varied between regions. We demonstrate that seascape connectivity can improve the performance of marine reserves across the western Pacific. We highlight its importance for maintaining ecological processes in reserves and advocate the prioritisation of areas of similarly connected habitat for conservation.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1040, Sebel Bluewater

Scaling up and down for effective marine spatial planning

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For marine spatial planning, both regional design and local action are crucial to achieving objectives, and both have complementary strengths and limitations. With regional designs, planners identify systems of areas that are complementary and functionally connected and so are more than the sums of their parts, but regional designs are only rarely translated into actions. Local actions are motivated, understood and informed by the communities most directly affected by the associated constraints on resource use, but local actions tend to form collections, not integrated systems. Combining design and action requires scaling up and down. Scaling up involves altering the location, extent, and configuration of local actions in order to achieve wider objectives. Scaling down involves changing regional designs in order to accommodate new information as actions are progressively applied. Scaling up and down are intuitive terms, but present planners and managers with challenges that are not well understood. This

presentation reviews the conceptual, operational, policy, and institutional implications of scaling up and down. The presentation raises questions about science and application that need to be addressed if marine spatial planning is to reach its potential in promoting the persistence of marine biodiversity and the continuation of livelihoods of people dependent on marine resources for food and commerce.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1000, Sebel Bluewater

Reconciling scales of social and ecological connectivity in conservation planning

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In regions where community-based management prevails, the development of marine protected area (MPA) networks has focussed on identifying effective approaches to scale-up local management initiatives to form systems that are more than the sums of their parts. Understanding the spatial scales at which social and ecological connectivity are relevant will be critical to these efforts. Social networks provide an incentive for communities to coordinate their actions across larger regions, and to establish management more extensively than they otherwise might. However, in the Coral Triangle region, the spatial scale at which social networks can be effective is defined by the presence of customary marine tenure and decentralised coastal resource management. Ecological MPA networks must be large enough to encompass processes such as larval dispersal and ontogenetic habitat use. The ability of social networking to act as a catalyst for the development of ecological MPA networks thus depends on the match or mismatch between spatial scales of social and ecological connectivity. Where the scale at which ecological processes occur exceeds that of social networks, management benefits might either be reduced, or realised by communities beyond the boundaries of the MPA network, thereby undermining support for management. Here, we review the spatial scales at which ecological processes and management institutions are relevant to MPA network design in the Coral Triangle. We identify contexts where congruence between social and ecological networks indicate that scaling up community-based actions will be an effective approach to achieve regional conservation objectives, and those where alternative approaches should be sought.

17C Regional-scale design & local-scale actions for marine conservation
Monday 9 July, 1015, Sebel Bluewater

Coral farming as means for sustaining livelihood and resource management

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With the ongoing transition between the barter and the cash economy in Papua New Guinea (PNG), traditional resource production and exploitation must adapt to the changing markets. The increasing demands for goods and services has resulted in coastal and marine resources in regions of PNG showing signs of overfishing and exploitation. Andra Island in Manus Province is one of many islands in PNG whose inhabitants are highly dependent on the sea for their sustenance and livelihood. Ecological studies by the Wildlife Conservation Society have revealed that the surrounding reefs are denuded of branching *Acropora* corals when compared with similar sites in Manus and elsewhere. This is likely to be closely linked to the island's economic dependence on the harvest of *Acropora* corals for the coral lime trade. Lime (calcium oxide) is chewed with betelnut (*Areca catechu*) throughout most coastal regions of PNG. A coral farming project was implemented with the aim of providing a sustainable means for maintaining the coral lime trade. Unlike other coral farming projects in the Pacific, this project operates completely at the local-scale and is therefore not reliant on overseas markets nor faces the transportation challenges of the aquarium trade. We assess here the degree to which the coral farming activities contribute to livelihoods while relieving extractive pressure on reefs. The project has potential to expand throughout the regions of PNG where corals are harvested for lime.

17C Regional-scale design & local-scale actions for marine conservation
P183

17D Managing bleached coral reefs

Effective community-based management of reefs faced with coral bleaching

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The mass bleaching event of 2010 was particularly devastating for the reefs of Thailand both on the Andaman Coast and throughout the Gulf of Thailand, with many areas experiencing between 95-100% bleaching. On the island of Koh Tao, in the Gulf, mass bleaching across all zooxanthelate corals was observed at every site around the island from the intertidal zone extending to more than 20 meters depth. By late May 2010, up to 98% of corals were bleached in the worst affected areas with mortality rates as high as 78%. Coral cover and diversity were dramatically reduced in many areas around the island, especially in the presence of other disturbances such as sedimentation, predation, and overgrowth. This paper documents the bleaching event of 2010 in high spatial and temporal detail, provides information on a wide range of potential environmental factors that contributed to the bleaching event and subsequent mortality, and also describes effective community based management programs which have been implemented on the island. These community-based management programs-enacted primarily without outside funding support- include creating local regulations and zoning, addressing land based threats, training professional divers in research and restoration techniques, creating coral nurseries or artificial reefs, predator removal, and more. Case studies describing the local management programs enacted before, during, and after the bleaching event are presented to stimulate protection and management of reef resources which have been greatly neglected in Thailand, and to provide models which are readily accessible and adaptable to other regions.

17D Managing bleached coral reefs
Wednesday 11 July, 1030, Sebel Kuranda

Characterisation of cceanic thermal anomalies in the Coral Triangle region

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Mass coral bleaching has historically been linked to episodes of thermal stress. Oceanic thermal anomalies, which underlie broad-scale thermal stress events, are considered to be on the order of hundreds to thousands of kilometres in their extent. There does not appear to be any existing quantitative study of the spatial extent, temporal development and intensity of oceanic anomalies. Knowledge on how these anomalies can be characterised may be useful in understanding how bleaching-level stress develops, providing context for future events. Here, we examine historical satellite sea-surface temperature (SST) data with the goal of characterising oceanic anomalies in the Coral Triangle region. This region is of interest as it includes influence from the Indian and Pacific Oceans and is the centre of coral diversity and significant coral reef conservation efforts. We define the oceanic anomalies using 2 metrics: SST anomaly (the difference in temperature from the climatological temperature for each location for that time of year) and Hot Spot (the positive variation in temperature above the maximum of the monthly mean climatology values). The latter metric describes thermal stress that has been linked to coral bleaching episodes. Data with multiple spatial resolutions are employed to evaluate if, and how, the characterisations are resolution-dependent. If these anomalies can be comparably identified at a coarser spatial resolution, this characterisation opens the door for examining oceanic thermal anomalies further back in time using historical datasets of lower spatial and temporal resolution. Furthermore, these characterisations may provide a useful descriptor for understanding climate model predictions.

17D Managing bleached coral reefs
Wednesday 11 July, 0945, Sebel Kuranda

The impact of coral bleaching at Mu Koh Similan National Park

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Coral reefs in the Andaman Sea are now under increasing pressure from marine tourism, especially snorkeling and SCUBA diving activities. The seawater temperature anomaly of 2010 also affected most coral communities. We aimed to examine limits of acceptable change of coral communities from tourist activities and the coral bleaching impacts at Mu Koh Similan National Park, a popular diving

spot in the Andaman Sea. Coral breakage was the most frequent damage category especially in shallow waters. The survey in December 2009 (before the high season) revealed that the average live coral cover was 65% and it decreased 2.7% at the end of high season. However, the survey in November 2010 (after the coral bleaching event) showed that average live coral cover was only 25.5%. The most susceptible coral species to bleaching were *Montipora* spp., *Acropora* spp., *Pocillopora* spp., *Seriatopora hystrix*, and *Porites* spp. Certain diving sites at Mu Koh Similan National Park have been temporarily closed in order to build resilience and to enhance coral recovery. Scientists and national park managers must work together closely with tourist companies and other stakeholders in order to carefully consider scenarios of coral bleaching impacts and coral reef ecosystem responses. Implementation of the science-based management plan for Mu Koh Similan National Park to cope with climate change and anthropogenic disturbances is essential.

17D Managing bleached coral reefs
P184

Recovery of corals on an intertidal reef after a aleaching event

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In April 2010, coral reefs across the southeast Asian and Indian Oceans were hit by the worst bleaching event in more than a decade. This event was also experienced by the corals at the intertidal reef at Teluk Datai Pulau Langkawi in the northern Straits of Malacca. The extent of bleaching-induced coral mortality was assessed at the upper and lower intertidal zones, by documenting the total percentage of normal, bleached, recovered and dead corals using transects. Two replicates of 25 m permanent transect lines were established in each zone for this purpose. Monitoring the coral recovery process was done for 5 months (July 2010 -January 2011). About half of the corals in the permanent transects were bleached during the event. Within 2 months, about 28% of the bleached coral turned to the recovery state. Another 22% of the coral died because of the high sediment load after the bleaching event, which inhibited the recolonization of the symbiotic zooxanthellae. Using a dataset of daily sea surface temperature and light intensity derived from loggers installed at the site, this study showed that the recovery process occurred during the period of wet season (August-November). This study also suggests that the local, natural stressors, such as sedimentation, cause less damage than the climate itself.

17D Managing bleached coral reefs
Wednesday 11 July, 1015, Sebel Kuranda

Tourist perception of coral bleaching in the Andaman Sea

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The mass coral reef bleaching event of 2010 has led to coral mortality in the Andaman Sea, Thailand. We aimed to assess socio-economic impacts and tourist perceptions of the 2010 coral bleaching event in Mu Koh Surin, Mu Koh Similan and Trang Province, in the southern part of Thailand, based on questionnaire surveys, secondary data sources and interviews with key informants. The surveys revealed that 52-91% of the tourists interviewed were aware of the 2010 coral reef bleaching event. Approximately 27-50% of tourists in the samples were SCUBA diving/snorkeling at the diving sites for the first time. The tourists mentioned that the diving was not as good as they expected it to be before coming to the islands. The averages (56, 26 and 19%) of tourists who have visited the 3 diving sites before said that SCUBA diving/snorkeling was not as good as they expected because of coral bleaching and they were happy to pay the extra fee of 10, 184 and 27 USD to see a better coral reef condition in Mu Koh Surin, Mu Koh Similan and Trang, respectively. About 85-95% of tourists interviewed said that they would like to visit the diving sites again. A proper management plan should be implemented with close collaboration from marine national parks and private companies in order to ensure sustainable tourism in the Andaman Sea.

17D Managing bleached coral reefs
P185

Understanding bleaching extent and severity through a networking: Indonesia example

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Indonesia is home to the world's most diverse yet threatened coral reefs. In addition to local threats, climate change is increasingly important. One of the biggest challenges to reduce these threats is the lack of an integrated management system supported by up-to-date information across the scattered archipelago of 17,500 islands. Developing a data network is considered an important tool to overcome this challenge. The effectiveness of networking was

demonstrated during the 2009- 2011 mass-bleaching event. The extent and severity of bleaching in Indonesia was determined from reporting of 55 different organizations and individuals, including local communities, across 14 provinces. Bleaching was reported at 61 sites, compared to ReefBase, which had reports from 4 locations. The first reports came from the middle of Indonesia (2009), continued to the west of Indonesia (2009-2010), and then the east (2011). In general, bleaching in northern part of Sumatra, Tomini Bay and South of Sulawesi were reported as the most severe. Meanwhile, the reefs east of Indonesia were the least severe. Importantly, reports were also obtained from sites that did not bleach. Both types of information are important for reef managers in understanding the different responses of reefs to increasing ocean temperatures. This information could serve as a foundation for management decisions or to trigger more comprehensive studies on bleaching. We are working to extend and strengthen this network in order to build a reef bleach watch alert system in Indonesia as a basis for expansion to the Coral Triangle.

17D Managing bleached coral reefs
Wednesday 11 July, 1000, Sebel Kuranda

Managing bleached coral reefs in the Gulf of Thailand

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Widespread and severe coral bleaching events on most coral reefs in the Gulf of Thailand were clearly documented in 1998 and 2010. The coral reef management and restoration project in tourist hot spots in the Gulf of Thailand was initiated and funded by the network of provinces along the east coast of Thailand. The project aims to survey and establish an ecological and socio-economic database for managing degraded coral reefs and enhance their resilience to climate change. In addition, artificial substrates for coral recruitment and ecotourism are provided at tourist hot spots, and participation of local communities in managing natural resources and environment, and public awareness and education are enhanced. The project shows effective collaboration between scientists, local communities, and local government officials as decision-makers to integrate scientific data into policy and adaptation practices. The coral reef restoration sites can be used to support ecotourism and learning rooms for students. Continuing efforts - in capacity building, public awareness and education through disseminating printed materials and conducting training courses, workshops and seminars for stakeholders, youth, students and local government officials - can enhance resilience in coastal communities. The project applies Thailand's coral reef restoration plan, comprising 4 strategies and 15 measures, which focus on passive restoration by reducing threats from tourism, water pollution, sedimentation and fisheries. Strengthening the long-term monitoring, evaluation and reporting of the project can provide lessons learned for conservation of coral reefs in tourist hot spots which are influenced by climate change, especially coral bleaching events.

17D Managing bleached coral reefs
Wednesday 11 July, 1035, Sebel Kuranda

Impacts of coral bleaching, recovery trends, and management in Thailand

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Severe mass coral bleaching events occurred on most reef sites in Thailand in 2010. Bleaching in the Andaman Sea was more severe and extensive than in the Gulf of Thailand. Several meetings, seminars, and conferences were organized by government agencies, NGOs and universities for gathering information on coral bleaching impacts, recovery trends, and management. Subsaquently, a list of recommendations for coral reef management in Thailand was developed. The important issues include: i) preventing coral damage from snorkeling in shallow reefs, sediment load from coastal development, wastewater discharge from boats and land-based activities into coral reefs, ii) creating temporary closures of diving sites,iii) establishing new diving sites, iv) conducting research and monitoring programs for coral conservation and restoration, v) informimg people and tourists concerning the status of coral bleaching, vi) providing sufficient man-power and budget to relevant government agencies, and vii) establishing effective networks of universities, government agencies, province offices, local administration offices, NGOs, private companies, and conservation groups. It is necessary to have effective mechanisms for project implementation under Thailand's national coral reef management plan. A list of research topics needed to

understand adaptation to coral bleaching was also provided by relevant experts and organizations. Development of young researchers and raising public awareness are urgently required for coral reef conservation in Thailand in order to manage the pressures and move societies to a sustainable pathway.

17D Managing bleached coral reefs
Wednesday 11 July, 0930, Sebel Kuranda

First quantitative assessment of coral bleaching impacts on Indonesian reefs

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There have been few quantitative assessments of the impact of coral bleaching events on Indonesian reefs and none published from Sulawesi. A four-year monitoring program (2007-2011) of coral condition in the Spermonde region of the Makassar Strait and on Buton reefs in the Banda Sea indicated that coral bleaching events occurred in 2009-2010. Here we provide the first overview of bleaching prevalence among coral genera in these 2 regions based on monitoring of 142 quadrats (50 cm x 50 cm) and 87 digital photos in Spermonde, and on 257 quadrats and 96 digital photos on Buton reefs. Bleached corals were dominated by species in genus *Acropora*, the families Faviidae, Poritidae, Pocilloporidae and Alcyonacea. The genera *Acropora, Diploastrea, Favia, Favites, Goniopora, Porites* and *Sinularia* were the most susceptible. The most resistant genera were *Turbinaria, Pachyseris, Symphyllia*, and *Heliofungia*. Sixty percent of coral species bleached in Spermonde and 58% on Buton reefs, resulting in live coral cover decreasing by 12.5% in the Spermonde region between 2009 and 2010. Partial mortality following bleaching was greater in Spermonde, where 24% of corals had live pigmented tissue, 28% had live bleached tissue, 39% had recently exposed white skeletons, and 10% were algal covered. In comparison, 42% of coral colonies on Buton reefs had live pigmented tissue, 16% had live bleached tissue, 17% had white skeletons and 26% were algal covered. Local fishermen first reported the bleaching in May, June, and July 2010 and consequently had reduced reef fish catches.

17D Managing bleached coral reefs
Wednesday 11 July, 1040, Sebel Kuranda

Theme 18. Management & monitoring

18A Evaluating management success

Long term monitoring, student research and MPA management, Caribbean

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Benthic and fish population surveys were completed annually by students in Grenada 2008 - 2011. This data collection is an educational opportunity, represents a biological baseline and provides valuable input into adaptive MPA management. In 2006 the government of Grenada pledged to protect 25% of terrestrial and marine resources by 2020. Significant progress towards these goals has been made in the past decade. Of note two MPAs were officially launched in 2010 and management plans have recently been implemented. Benthic and fish data collected over the past four years indicate that coral communities in Grenada are degraded. Despite MPA status, these reefs remain vulnerable. Climate change poses an array of threats to the citizens and environment of the nation of Grenada; these effects are already apparent and future predictions are of extreme concern. Analysis of student data has already informed decisions of the MPA stakeholder committee and has been utilized to raise public awareness of marine issues. Existing and future data will be invaluable for effective MPA management. Furthermore, the data is a hugely important resource for multiple stakeholders in Grenada and all nations that are committed to the Caribbean Challenge (to protect and effectively manage 20% of marine and terrestrial resources by 2020). Annual surveys are planned for the foreseeable future. Data from this project is important to a nation with limited financial and technical resources and will be valuable in monitoring the health status of these reef systems and in determining the efficacy of MPA management in the future.

18A Evaluating management success
Tuesday 10 July, 1030, Hall B

Recreational fishers' compliance in the Great Barrier Reef Marine Park

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Understanding recreational fishers' compliance with no-take zones is essential to successful management in the Great Barrier Reef Marine Park (GBMRP). The random response technique (RRT) was used for assessing recreational fishers' compliance with Green Zones in the GBRMP. The RRT allowed the researcher to ask a sensitive question ('Did you, knowingly, fish within in a Green Zone during the last 12 months') in a manner designed to protect respondents' confidentiality. A survey was conducted to measure and understand recreational fishers' compliance and to test the RRT for possible further applications. Additionally, fishers' beliefs and attitudes regarding green zone compliance were examined to understand compliance drivers. Compliance was high (90%) and mostly driven by beliefs about non-compliance penalties. Also, a positive perception of legitimacy towards the Zoning Plan was detected among fishers, potentially fostering voluntary compliance. RRT proves to be practical, economically and logistically, for studying angler compliance in the GBRMP. The study has management implications. First, it indicates that past and current compliance-related communication efforts by the Great Barrier Reef Marine Park Authority have succeeded in maintaining appropriate compliance levels. Second, future communication efforts should accentuate environmental and social beliefs that will sway users to comply voluntarily because it is the 'right thing to do', not to avoid being punished. Third, monitoring compliance levels and drivers should be integrated into the adaptive management of the GBRMP.

18A Evaluating management success
P186

Effectiveness of sanctuary zones in the Ningaloo Marine Park

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This project used a broad range of approaches to assess the effectiveness of management of the multiple use Ningaloo Marine Park. In 2006 no-take zones were increased from approximately 5% to over 30% of the park but there was little or no change in fisheries management. In general, we confirmed that the original zoning implemented in 1991 has achieved positive outcomes in terms of biodiversity protection and that the recent rezoning is likely to achieve further conservation outcomes as intended. For example, assessments of fish populations across a range of previously established sanctuary zones revealed higher biomass of several targeted species (lethrinids and serranids) across multiple sanctuary zones.

However results also suggest the need for ongoing evaluation of marine park effectiveness in relation to both zoning and overall management. Biomass of sharks, trevallies, groupers and emperors varied more in relation to broad in fishing pressure gradients than in relation to zoning, and limited historical data suggest densities of spangled emperor are lower now than at park creation. Tracking of fish using acoustic tagging at Ningaloo have provided information that rates of cross boundary movement are significant and some important species preferentially use habitats that have been selectively excluded from no-take zones in order to provide for a range of human activities. Taken together these results indicate that aspects of previous park configuration required further action in order to realise park management goals and it is likely that such actions need to be coordinated across both fished and unfished zones.

18A Evaluating management success
Monday 9 July, 1500, Hall B

Management of the Great Barrier Reef: a success?

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Current coral cover across the Great Barrier Reef (GBR) is about 20%. This is a reduction of approximately half since the 1960s. The GBR Marine Park Act was enacted in 1975 and GBRMPA established. So why has coral cover continued to decline when the GBR is being managed with a management regime often recognised as 'the best managed coral reef system in the world'. The stressors which are believed most responsible for the loss of coral cover, general 'reef health' and resilience are terrestrial pollution including the link to crown of thorns starfish, fishing and climate change. However the management response after 1975 did not concentrate on these issues but instead on zoning, with restrictions on fishing in limited areas and tourism management. Significant action on fishing, including trawling, did not occur until the trawl management in 2000 and the rezoning of 2003. Effective action on terrestrial pollution did not occur until the Reef Rescue Initiative of 2008. Effective action on climate change has yet to begin either nationally or globally. Thus it is not surprising coral cover on the GBR has reduced to values similar to those seen in other coral reef areas such as Indonesia and the Philippines. However it can still be credibly claimed that the GBR is the best managed coral reef system in the world but it must be realised that this is a relative assessment against other reef systems and management regimes and not an absolute claim for effective management.

18A Evaluating management success
Monday 9 July, 1130, Hall B

Measuring and communicating effects of MPA's on deep 'shoal' fisheries

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Counts by divers have shown a rapid rise in coral trout populations on shallow reefs of the Great Barrier Reef Marine Park closed to fishing in 2004, but the deeper line-fishing grounds have been inaccessible to fish biologists until the development of multibeam swathe maps and baited video techniques. In this talk I will present four years of data counting and measuring prized sportfish, line-fishing bycatch and unfished species from three types of 'shoal ground' with 'Baited Remote Underwater Video Stations' {BRUVS} that can film down to 100 metres and are made from cheap components. The results of paired 'fished-unfished' contrasts all depended on the context of microhabitat type, proximity to fishing ports and species vulnerability to linefishing. On some diffuse, low-relief grounds prized target species were actually less abundant in zones closed to fishing. On some discrete sunken banks there were about twice as many prized species. The pattern around the deep bases of some reefs were not visible unless different habitat types were accounted for. Everywhere reef sharks were more abundant in zones closed to fishing. I will illustrate these differences with novel point-and-click map-based products on the 'e-atlas', using GoogleEarth and YouTube, that let the public make up their own minds about the local effects of marine protected areas - a picture speaks a thousand words.

18A Evaluating management success
Monday 9 July, 1630, Hall B

Florida Keys National Marine Sanctuary presents its 'condition report'

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The National Marine Sanctuary Program (NMSP) of the National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS) manages United States marine areas in nearshore and open ocean

waters that range in size from less than two to almost 362,598 square kilometers (140,000 square miles). Sanctuary managers and staff have a variety of tools at their disposal to help them protect site resources. However, resource managers are being increasingly challenged to defend their decisions with scientifically credible data. NMSP has implemented a new, peer reviewed reporting tool called a 'condition report' to ensure the timely flow of data and information to those responsible for managing and protecting resources in the ocean and coastal zone, and to those that use, depend on, and study the ecosystems encompassed by the sanctuaries. Florida Keys National Marine Sanctuary (FKNMS) is one of the largest of these marine protected areas, encompassing 9,933 square kilometers (2,896 square nautical miles). Though FKNMS was established by US law in 1990, only since 1997 have marine zones for multiple uses, including 24 highly protected 'no-take' areas (6% of the sanctuary) been in place. We present the FKNMS 'condition report' of 2011, which provides a summary of its resources, pressures on those resources, current conditions and trends, and management responses to the pressures that threaten the integrity of the Florida Keys marine environment. This information is guiding a public process, which is the first comprehensive review of the FKNMS regulations, its marine zoning scheme, and its management plan

18A Evaluating management success
Monday 9 July, 1215, Hall B

Managed access: moving towards collaborative fisheries sustainability in Belize

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The Belize Fisheries Department (BFD) is leading a coalition with the Toledo Institute for Development and Environment (TIDE), Wildlife Conservation Society (WCS), Environmental Defense Fund (EDF) and Belizean fishers, to explore Managed Access as a fisheries management policy for Belize. This is in response to concern over increasing numbers of fishers, decreasing fish landings, and illegal fishing by Guatemalan and Honduran fishers, who sell Belizean marine products outside Belize, bringing no benefit to Belizean communities. Managed Access limits access to General Use Zones within reserves, restricted by a licensing system to 'traditional fishermen', as defined via community consultation with guidelines produced by BFD. Program effectiveness is measured via collection and analysis of catch data from licensed fishers. Two pilot sites have been selected; Port Honduras Marine Reserve (PHMR), comanaged by BFD and TIDE, and Glover's Reef Marine Reserve (GRMR) comanaged by BFD and WCS. The program, launched in July 2011 in both reserves, will run for two years, and if successful will be introduced in all MPAs in Belize. Pending continued success, a Catch Shares management system will be incorporated, using market-based incentives to align fishers' economic interests with conservation outcomes. However, concerns are already being raised over the process by which licences are issued or denied, with some fearing that loopholes and weak enforcement will erode public confidence in the program. The coalition needs to be highly responsive to the emergence of weaknesses in the current design, to ensure continued buy-in, and ultimately, permanent transition towards Managed Access nationwide.

18A Evaluating management success
Monday 9 July, 1730, Hall B

Addressing environment management and local livelihood in Fiji's coastal communities

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Since 1997, interested coastal communities in Fiji together with a network of conservation practitioners, the Fiji Locally Managed Marine Areas, have been working in partnership to collectively address threats to their natural resources, especially in Fiji's inshore waters. A major driving force for this movement is the need to conserve marine biodiversity for use by future generations and to ensure human wellbeing in these communities. Achieving wellbeing in this context encompasses a whole range of social dynamics such as income, human development, empowerment, governance and social relations which in turn, are also key indicators for poverty reduction assessment. This study strives to understand the impacts of these conservation programs on the livelihood of these coastal communities and also the driving force within these communities that can determine the achievement of conservation and poverty reduction goals. The results imply that conservation of resources not only improves biodiversity but more importantly, it improves the social elements and dynamics that make a community function. It is recommended to encourage resource conservation in-order to improve productivity and reduce poverty. Also, it is recommended that these two issues should be addressed in parallel by practitioners to ensure the long term success of these initiatives.

18A Evaluating management success
Monday 9 July, 1530, Hall B

Evolving MPA monitoring to meet policy & management needs

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Implementation of MPAs and MPA networks has increased dramatically in the last decade, fueled by practical demonstrations that this management tool can restore or protect species, habitats, and associated ecosystem services. As part of this process, the scientific theory underlying MPA network design has flourished. However, our understanding of how to evaluate MPA performance remains limited. MPA monitoring often emphasizes assessing differences in densities and sizes of organisms inside and outside MPAs, which is insufficient to assess progress towards broad ecosystem protection goals. We have developed a monitoring framework that adopts practical indicators to track ecosystem condition and evaluate the ecosystem-wide effects of MPA network implementation. This approach is being applied and refined using the extensive network of coastal MPAs in California as a test case. While responsive to an ecosystem-based policy framework, the framework pushes the limits of scientific knowledge and will require testing and refinement over time. Direct measurements of resilience, ecosystem dynamics and diversity are often unknown or not feasibly implemented; currently practical alternatives incorporate multiple trophic levels, habitat and other key attributes. The monitoring framework is designed to both promote and respond to increasing scientific understanding of the factors maintaining healthy, resilient marine ecosystems. It provides a path towards performance evaluations that meet policy mandates and enable adaptive management. Through this demonstration, we are not only poised to meet regional management needs, but also to provide a blueprint for monitoring ecosystem condition that can be applied elsewhere.

18A Evaluating management success
Tuesday 10 July, 0945, Hall B

Effectiveness of no-take marine reserves after 15 years, Nabq, Egypt

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After establishment of a network of small No Take Zones (NTZ) in 1995 in Nabq traditional reef fishery, a build up in numbers of commercially targeted fish species was reported 5 years and 10 years later. Underwater visual census of NTZs in 2011 showed a reduction in the total abundance of Serranids and Lutjanids. Catch records showed that mean CPUE in 2010 (1.02 kg/net.hr) has decreased than in 2000 (1.31 kg/net.hr), though still higher than before reserve establishment (0.79 kg/net.hr). The number of fishermen and total fishing effort has gradually increased in fishing grounds during the last 10 years. NTZs were also exposed to low levels of fishing from occasional pouching by visiting fishermen and younger generations. The success of the network of small NTZs in maintaining the sustainability of the fishery since 1995 was dependent on the cooperation and involvement of local Bedouin fishermen in a community based fisheries management program. At present, escalating fishing effort is increasing pressure on marine resources. Raising fishermen awareness to impacts of overfishing and benefits of maintaining NTZs while involving them in day-to-day fishery management should encourage sustaining fishing effort at, or below, present levels. Further, providing alternative livelihoods for the fishermen and their families could significantly reduce fishing effort to sustainable levels. The effectiveness of the size and location of established NTZs is reviewed and recommendations for rotation of closed and open fishing grounds are discussed.

18A Evaluating management success
P187

Reef community structure in Marine Protected Area in Southern Philippines

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Evaluating the effectivity of marine protected areas (MPAs) as a fisheries management tool is constrained by the lack of reliable data in relevant time-series comparisons. A number of MPAs in northern Mindanao established around year 2000 were evaluated under the RESILIENT SEAS program for climate change research. Results show that positive trends in coral cover were observed in the Gosoon and Cahayagan MPA, Carmen, Agusan del Norte and Omangon Is. MPA, Marihatag, Surigao del Sur since 2000. The highest mean hard coral cover was observed in May 2011 in Cahayagan (59.80%) and the highest overall reef fish abundance occurred in Gosoon (8370 ind/1000 m^2) in August 2009, while the highest biomass was found in Omangon Is. (79.64 kg/1000 m^2) in August 2010. In general, Omangon Is. consistently had the highest average fish biomass but lowest in abundance and species richness during southwest and northeast monsoon compared to Gosoon and Cahayagan MPAs. Time-series data show an apparent seasonality in diversity and abundance of fish communities in all sites. Changes in coral and

fish community structure over time, on the other hand, can be a consequence of inconsistencies in assessment methods and differences in level of enforcement. To minimize wide variabilities in coral and fish community data, standard monitoring techniques should be adopted for long-term monitoring of MPAs. Despite their limitations, present results can be used for improved MPA governance in the study sites.

18A Evaluating management success
Tuesday 10 July, 1015, Hall B

Sustainability and status of a women ornamental fishing cooperative

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The sustainable exploitation, management and conservation of marine resources, when associated with coastal communities that depend on them for survival or economic well-being, can be difficult to achieve. However, there are models which are currently 'successful', as is the studied case here about ten women who created an ornamental fishing cooperative called 'Mujeres del Golfo' in Ligüi, a coastal community in Baja California, Mexico. In February, March and April 2011, a study of socio-economic conditions of these ten members was conducted using a closed semi-structured questionnaire. In order to determine the current status of their company, a SWOT analysis was carried out in a participatory manner with them in November 2010. To determine the level of human development of the community and the sustainability of this fishing activity, socio-economic indices, originally developed by the United Nations but reduced to a local scale and specifically adapted to fisheries were calculated. A SWOT matrix was designed with the results of the participatory workshop and strategies that could be adopted by the partners to better establish their business were highlighted. In parallel, the women from the cooperative and some community residents of Ligüi were submitted to interviews and surveys with opened semi-structured questions. The results show a change in mentalities about gender and fisheries, a different perception of environmental problems and conservation of marine resources among the community, and the important role and help that can provide civil organizations and Marine Protected Areas to reach sustainable objectives.

18A Evaluating management success
Monday 9 July, 1030, Hall B

Changes in coral coverage in the Eastern Indonesia during Coremap2

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COREMAP (Coral Reef Rehabilitation and Management Program) is a long-term program initiated by the Government of Indonesia with the objectives to protect, rehabilitate, and achieve sustainable use of the Indonesian coral reefs and their associated ecosystems which, in turn, enhance the welfare of the coastal communities. COREMAP Phase 2 started in 2006 and finished in 2011. During these years, reef health monitoring has been conducted in seven districts of COREMAP located in the eastern region of Indonesia. Those districts are: Pangkep, Selayar, Buton, Wakatobi, Sikka, Biak and Raja Ampat. The aim of this study is to evaluate the impact of COREMAP Phase 2 based on the condition of coral reefs. Permanent transects were applied at each district and their position was recorded by GPS. The results showed that live coral cover at Biak District tended to decline primarily due to storm damage with additional destruction by bombs and some limited bleaching.

18A Evaluating management success
P188

Tangible benefits of marine park management for human well-being

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The Great Barrier Reef World Heritage Area constitutes a rich source of economic, social and cultural goods and services of benefit to local, national and international communities. Undoubtedly the Great Barrier Reef makes significant contributions to local and national economies. Effective marine park management includes protection of those ecosystem goods and services, but we are only beginning to comprehensively measure the effectiveness of management strategies in that light. Identifying and assessing tangible benefits of marine protected areas to society is a critically important way of generating much-needed support for long-term marine conservation. The Great Barrier Reef Marine Park Authority has a number of initiatives that are shaping a

framework to assess the contributions of effective marine park management to human well-being including Indigenous partnerships; community engagement and stewardship; climate change; sustainable use of marine resources; catchment and coastal processes; water quality; tourism and recreation; and science coordination and communication. The initiatives are guided by two key questions posed in the Great Barrier Reef Outlook Report: 1.What are the current state and trends of the Great Barrier Reef's environmental, economic and social values? 2.What is affecting the Great Barrier Reef's environmental, economic and social values? Together with our research partners from CSIRO and James Cook University, the Great Barrier Reef Marine Park Authority has developed an approach to answer these questions.

18A Evaluating management success
Monday 9 July, 1715, Hall B

Effectiveness of different levels of management on three Belizean MPAs

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Coral reefs worldwide are degrading at an accelerated rate. Coupled with predictions of near-future climate change, increased coastal development and increased dependence on reef resources, the future for coral reefs looks bleak. The need for improved management is paramount in order to preserve reefs for the future. Belize hosts the longest barrier reef in the Western Hemisphere, which forms part of the Mesoamerican Reef (MAR) system. In addition to climate change threats, localized risks to reefs within this area include over-fishing, coral disease, and coastal and caye development. An effective network of marine reserves with good connectivity between sites is essential. Marine Protected Areas have the ability to act as 'stepping stones' allowing larval supply and dispersal from one region to another. Southern Environmental Association co-manages 3 Marine Protected Areas within the Southern Belize Reef Complex; Laughing Bird Caye National Park (LBCNP), Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Sapodilla Cayes Marine Reserve (SCMR). The three reserves exhibit a gradient in their level of protection, ranging from a fully protected no-take national park, to a marine reserve with established zoning, to a marine reserve with new zoning that has only been enforced since 2010. Abundance and size data for commercially important species (conch, lobster and certain fish) is presented and results are displayed over time in order to show the effectiveness of the differing levels of management. The future of these southern Belize reef ecosystems is considered in the context of future threats and potential management strategies.

18A Evaluating management success
Tuesday 10 July, 0930, Hall B

Modeling the economic benefits of temporary octopus fisheries closures

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A local fisheries management model employing short-term fisheries closures for rapidly growing species is proliferating across coastal east Africa and Indian Ocean islands. Aiming to improve management and boost incomes, NGOs, international finance institutions, and government agencies are promoting the technique in artisanal fishing communities. In southwest Madagascar alone, over 100 such closures have been implemented. To-date, no study has analyzed the closures' effects on fisher incomes. This paper uses over 250,000 datapoints gathered over 8 years to investigate the economic effects of octopus fishery closures in the Velondriake Locally Managed Marine Area in southwest Madagascar. First, we examine village-scale octopus fishery-generated income before, during, and after closures. The villages saw no significant revenue decline during the closure, but do show significantly higher revenues post-opening. Second, we use a stochastic model, parameterized with landings data, to assess whether each closed site was a profitable investment on its own. Of the 37 closures, 28 were profitable and 9 were unprofitable by this strict criterion. In 8 of the 9 unprofitable cases, stealing was recorded, and in 6 cases stealing was rampant. Third, we calculate each closure's internal rate of return (IRR), showing that the median monthly IRR in the 28 profitable closures was 67.7% (+/- 29.9% CI95). Examining gender bias in closures' costs and benefits, we found that women disproportionately stop fishing octopus during closures and men disproportionately fish during opening-day derbies. While significant, the changes are slight and the proportion of females never drops below 50%.

18A Evaluating management success
Monday 9 July, 1700, Hall B

Effectiveness of small MPAs in Palau in meeting fisheries objectives

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Bigger MPAs are generally more effective than smaller MPAs, but most of the MPAs around the world are small. To determine effectiveness of small MPAs in meeting their objective of improving fisheries resources, we studied four small MPAs in Palau, western Pacific. Underwater surveys were conducted to obtain fish density and biomass data inside and outside the four MPAs. Our results showed that there was no significant difference in the density of fish in the MPAs (22.9 ± 3.5 Mean ± SE) compared to the reference sites (25.0 ± 3.0). The biomass data showed similar results with no significant difference inside the MPAs and their reference sites. In order for small MPAs to be effective, active and adaptive management is necessary. We conclude that for small MPAs in Palau, and around the world, to be effective in meeting their management objectives, all aspects of management need to be improved.

18A Evaluating management success
Monday 9 July, 1230, Hall B

Assessing co-management in protected areas in the Northern Territory: lessons for Marine Protected Areas

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Over the last two decades, evaluation of management effectiveness of protected areas has been increasingly applied at sites around the world. However, to date there has been no research on the effectiveness of co-management between government and Indigenous peoples, or of its cost, although such arrangements are becoming increasingly prevalent. In this paper we describe and present results of a participatory action research collaboration between the Northern Territory (NT) Parks Service, Traditional Owners and the Northern and Central Land Councils to build a participatory monitoring and evaluation (PM&E) framework for assessing joint management (a type of co-management) of four protected areas in the NT. We present the framework developed, indicators identified by partners and the financial costs and benefits associated with the implementation. The results demonstrated similarities across parks in the types of indicators (e.g. social, cultural, economic, ecological, and governance elements) selected by partners to measure joint management. We found the costs of carrying out a participatory monitoring and assessment of joint management are minimal against the overall costs of joint management. We also found that the benefits of a participatory assessment extend further than just collecting information for management of the park, building trust amongst co-management partners, improving communication and establishing a cycle of feedback and revised action. We share some of the lessons from this research project and identify how such a framework could be applied to co-management of marine protected areas or other forms of PAs in similar contexts.

18A Evaluating management success
Monday 9 July, 1200, Hall B

Herbivore enhancement as a tool for reef restoration

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In July 2009, the Hawaii Division of Aquatic Resources designated Kahekili Reef, Maui an Herbivore Fisheries Management Area (HFMA), banning the removal of herbivorous fishes and urchins in an effort to promote herbivore grazing and thus reverse the decline in coral cover on the reef. Land-based nutrient loading and overfishing have likely led to the increase in algal cover and 40% decline in coral cover at Kahekili over the past 15 years. To provide management targets for reef recovery, we created a production/consumption budget by assessing seasonal algal growth rates, herbivore grazing rates and preferences, and herbivore populations when the HFMA was designated and in the subsequent two years. Herbivorous fish and urchin grazing rates indicated clear preferences for different species of macroalgae among herbivores, though the majority of grazing occurs on turf algae. Fishes and urchins graze typical blooming algal species an order of magnitude faster than non-blooming algae and preferentially graze nutrient-enriched algae. These preferences suggest that an increase in herbivore biomass due to protection could be effective in reducing algal abundance, especially for blooming and nutrient-enriched algae. Presently, algal production at KHFMA exceeds the grazing capability of the herbivore community. Therefore, future increase in herbivore biomass will be essential to improving reef health and increasing reef resilience to global stressors. A similar approach to this study could be used to establish management targets for other reefs and the success of the HFMA could provide a model for coral reef management.

18A Evaluating management success
Monday 9 July, 1035, Hall B

Invasive alga removal accelerates sediment flushing in Maunalua Bay, Hawaii

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Invasive species are a worldwide problem and have altered both terrestrial and marine ecosystems in Hawaii. *Avrainvillea amadelpha* is one marine invader that has changed the Paiko Lagoon Peninsula (PLP) reef flat ecosystem. PLP also has a sediment accumulation problem worsened by the dense presence of the alga. Community-based groups, in partnership with governmental agencies, have attempted to restore PLP by manually removing 2374 tons covering 25 acres of *A. amadelpha*. This study investigated the effectiveness of this restoration approach in the removal of accumulated fine sediment at PLP. We collected data at least once monthly for 13 months using a sediment resuspender and turbidity meter. Data collected before large south swells in August and September 2011 suggested little to no export of fine sediment out of PLP. The removal of *A. amadelpha* effectively 'released' fine and coarse sediment, but with no flushing events, the sediment was trapped within the study site. Following the wave events, fine sediment concentrations decreased in the cleared areas of PLP. Our data suggests that the dense presence *A. amadelpha* contributed to sediment retention. Our model found that with algal removal and two large wave events, the flushing time of fine sediment was reduced from approximately 6.5 to 4.75 years. Although restoration can be challenging and slow, success can still be achieved through effective community and governmental partnerships. The removal of *A. amadelpha* is the first step in improving habitat quality at PLP.

18A Evaluating management success
Tuesday 10 July, 1000, Hall B

An ecological approach to determine divers quota in Sipadan Island Park, Semporna, Sabah, Malaysia

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Sipadan Island, Sabah, Malaysia is internationally renowned as one of the favourite SCUBA diving destinations. The island is now gazetted as Marine Park and managed by Sabah Parks. Presently, only a maximum of 120 divers or visitors are allowed to visit Sipadan in a day. Dive operators usually drop divers from their boats near the reef front at any of the 12 drop points in Sipadan. However, most operators prefer to bring divers to only three or four dive sites, namely, Barracuda Point, Drop-Off, Mid-Reef, and/or South Point where chances of divers encountering large schools of Sipadan's iconic species, namely the barracuda (*Sphyraena putnamiae*), bumphead wrasse/parrotfish (*Bolbometopon muricatum*), and jackfish (*Caranx sexfasciatus*) are perceived to be greatest. The high number of divers to these sites had caused significant damage to hard corals than other less preferred sites. On contrary, there were also reports that the iconic species have been sighted at other dive sites around Sipadan. The management perceives that the dive operators are not bringing divers to other sites due to distance and as a fuel-cost saving measure. Hence, Sabah Parks has embarked on an ecological study to understand the movement of the iconic species in Sipadan with the hope of providing evidence and convincing the dive operators and divers that the iconic species can be sighted throughout Sipadan. This paper describes the additional reconciliatory step taken by the park management to make the divers and dive operators understand how and reasons why certain management measures are made.

18A Evaluating management success
P189

Assessing the effectiveness of water quality management of the Great Barrier Reef

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Halting and reversing declining water quality is a key strategy for maintaining the resilience of coral reefs world-wide and a major priority for the effective management of the Great Barrier Reef (GBR). Under the Australian and Queensland government's Reef Water Quality Protection Plan, the 'Paddock-to-Reef Integrated Monitoring, Modelling and Reporting Program' provides a framework for adaptive management that links land management

activities in the catchments to assessments of the water quality and ecosystem health of the GBR. Key aspects of the program include ambitious, quantitative targets for land management practices and pollutant loads; integration of formerly disparate monitoring and modelling efforts within a common reporting structure; and collaboration between multiple stakeholders with often-competing interests. The reporting format presents and integrates key indicators in a transparent manner at the paddock, catchment and marine scales. Marine indicators are generated by the Reef Rescue Marine Monitoring Program and target water quality, seagrass and coral health. The First Report provides a baseline assessment of the condition of the reef using multiple lines of evidence against which long-term progress towards management targets and goals may be evaluated. Inherent challenges of the task include a large-scale, spatially and temporally heterogeneous ecosystem that crosses multiple jurisdictions. A long time-lag is expected before any improvement in the water quality of the GBR will translate into measureable changes in ecosystem function. However, the coordinated approach and effective partnerships are expected to generate outcomes that engender improvement and promote more harmonised policy development across political jurisdictions.

18A Evaluating management success
Monday 9 July, 1145, Hall B

Effectiveness of adaptive, spatial management on the Great Barrier Reef

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A key aspect of success in conservation lies in our ability to get better as we go, and learn from our mistakes and our successes- that is to adaptively manage. As we increase efforts, we need to ensure that we continually improve our effectiveness in slowing the global decline in reefs. This means accepting that we won't get it right first time every time, and that we need to build on successful strategies and improve on unsuccessful ones. The scientific literature includes many assessments of marine conservation problems and mistakes, especially the literature on marine protected areas, but there's a tendency to see the glass as half empty and throw up our hands. It's really important to assess the successes as well, the glass half full perspective. The Great Barrier Reef provides a globally significant demonstration of the successes that can be achieved through carefully planned and implemented networks of marine reserves and ecosystem-based management. Available evidence on the effects of the network of marine reserves on the Great Barrier Reef suggests that there have been benefits for fishes, sharks and even corals and hard to protects species such as dugong and turtles. Overall, that the network appears to be making major contributions to the protection of biodiversity, ecosystem resilience and social and economic values of the GBR Marine Park. Importantly, there are likely benefits for fisheries, as well as biodiversity conservation.

18A Evaluating management success
Monday 9 July, 1000, Hall B

Evaluating reef health and management response in the Mesoamerican Reef

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The Healthy Reefs for Healthy People Initiative (HRI) is a collaborative international initiative of over 35 local and international organizations that aim to conserve the Mesoamerican Reef. Standardized reef monitoring occurs across the four countries, followed by presentation of results in biennial Report Cards that include recommendations for improving reef management. The ecosystem-based Report Cards are followed by biennial Eco-audits that measure the collective response of government, NGO and private sector in implementing these stronger reef management actions. The 2010 Report Card found that only 1% of reefs were ranked in 'very good' condition; with 8% 'good'; 21% 'fair'; 40% 'poor'; and an alarming 30% of reefs ranked in 'critical' condition. These results were based on 130 reefs evaluated with four indicators of reef health (coral cover, fleshy macroalgal cover, herbivorous fish biomass and commercial fish biomass), combined into a Reef Health Index. The overall ranking (2.1) was 'poor' in the 2010 Report Card versus 'fair' (2.7) in the 2008 Report Card. The decline was mainly attributed to declining commercial and herbivorous fish biomass and increasing macroalgae. Coral cover actually increased during this interval which had no major disturbance events. The Report Card recommendations serve as the basis of the Eco-audit process, which is finishing in late 2011. Several reef management actions have been adopted, while many others have not made substantive progress. The combination of ecosystem and human-focused evaluations presented in user-friendly communications presented with broad media coverage, offers a collaborative process for turning the tide of reef decline.

18A Evaluating management success
Monday 9 July, 1515, Hall B

Evaluating refuge volumes provided by habitat-structuring benthos and substrate

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An important factor influencing the composition of coral reef ecological communities is the provision of refuge volume for a variety of mobile organisms across a range of growth stages. Its determination has particular significance to mitigation cases wherein the replacement of lost ecological functions is mandated. Field assessments often incorporate estimation procedures which provide aggregate indicators related to this factor, such as rugosity or coral surface area. However, important refuges such as overhangs are not usually accounted for, and the refuge volumes are difficult to isolate from other factors. We introduce here an assessment approach based on simple geometry which is applicable to substrate and habitat-structuring organisms. The relationships among various types of refuge volumes and predator-prey size ratios are explored using computer simulations. The estimation approach is demonstrated using empirical data, and recommendations are made for relevant data-gathering in future studies.

18A Evaluating management success
Monday 9 July, 1545, Hall B

Monitoring by non-governmental organizations for marine conservation management in Indonesia

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Non-governmental nature conservation organizations (NGOs), especially those operating in developing countries, often take a special interest in monitoring of ecological and socio-economic indicators. Usually, NGOs state two objectives for monitoring: informing adaptive management, and measuring management performance. In this paper, we review to which extent monitoring programs related to coral reef and sea turtle ecology in Indonesia have achieved these two objectives over the past two decades, and we provide suggestions for improving effectiveness. We argue that management-oriented monitoring must aim to provide estimates for the true value of state or rate variables and their variation within the area-of-interest rather than attempt to provide quasi-experimental data for hypothesis testing. We find that management-oriented monitoring is fundamentally different from research-oriented data collection, where management-oriented monitoring requires more attention to spatial coverage of observations, to logistic and practical constraints, and to the needs and capacity of partners. We emphasize that management-oriented monitoring is critical to conservation management, not only to achieve its two main objectives, but also to increase field presence of management staff.

18A Evaluating management success
Monday 9 July, 1015, Hall B

Validate indicators for performance management of the Reunion Island's MPA

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The objectives of marine protected areas (MPA), such as Reunion's Marine Reserve (RNMR) founded in 2007, are (i) protect habitats and resources from increasing pressure due to a major urban, economic and recreational development; and ii) manage uses and conflicts between traditional fisheries, spearfishing, diving and recreational activities inside the coastal zone. These goals necessitate monitoring tools such as indicators and diagnostics. The PAMPA programme involves seven MPA including the RNMR. It aims to identify and validate indicators according to management objectives and group them in a MPA performance dashboard. This panel will help to visualize temporal trends and define threshold values between different levels of MPA performance. The data used in the analysis are related to natural resources and biodiversity (corals, fish, habitats), uses (traditional fishing and commercial) and governance (administrative and financial data, users perception surveys). These data involved the definition of a common species classification scheme, the compilation of geographic distribution data and the harmonisation of databases to allow cross-analysis. This program had allowed testing indicators (to target relevant indicators) and the implementation of a dashboard with trends, thresholds and performance classes. Continuous cooperation between managers and scientists throughout the project, around RNMR and with other MPA sites, allowed a permanent transfer of the program's progress

towards managers. They were able to integrate the results of the programme to define the framework of their first management plan.

18A Evaluating management success
Monday 9 July, 1115, Hall B

Marine Conservation Agreements: combating resources decrease in Raja Ampat, Indonesia

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In Indonesia, marine protected areas (MPAs) cover 13.5 million ha of coastal and offshore waters. Most of Indonesia's MPAs are managed for multiple uses through zoning plans which include 'no take' zones (NTZs). However, few MPAs are effectively managed and compliance with NTZs is low which may be partly due lack of community involvement in the zoning plan development. Marine Conservation Agreements (MCAs) are an innovative strategy which can be used to establish NTZs based on legal agreements between the legal and/or traditional owners of the area and conservation-minded entities, including industry. Southeast Misool MPA is part of the Raja Ampat MPA network in West Papua and is designed to protect the world's most diverse coral reefs. In 2005, over 40,000 ha of the MPA were designated as a NTZ through an MCA between local communities and the Misool Eco Resort. The local communities agreed to lease the area to the resort in return for lease payments, education and patrol facilities. As a result, harvesting of marine resources stopped in 2007 within the leased NTZ. Since 2009, annual reef monitoring has been conducted at multiple sites inside and outside the MCA area using point intercept transects (benthos) and Underwater Visual Census (fish and sharks). Preliminary results suggest that coral cover and shark abundance have improved inside the MCA area compared to sites outside. This study indicates that MCAs are a promising tool to improve both the livelihoods of local communities and the management effectiveness of MPAs.

18A Evaluating management success
Monday 9 July, 1645, Hall B

The effectiveness of locally managed marine areas in Fiji

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Marine resources, the mainstay of most Pacific Island peoples livelihoods have been dwindling rapidly over the last several decades. Creating locally managed marine areas (LMMA) is one such effort to reverse this trend that utilizes community based adaptive management (CBAM) process, based on progressive participatory community-driven approaches informed by marrying scientific and traditional knowledge. Despite the widespread promotion of LMMAs in Fiji over the last 15 years, their role and effectiveness remains contested. Hence, this paper focused on the key question: to what extent does LMMA work as a practical and useful approach to marine conservation in Fiji? The progress of scaling up LMMAs to national level across 300 Fijian communities is first reviewed. Both empirical and experiential evidences on successes and challenges of LMMAs are also presented. Household incomes have improved by as much as 30%, fish catches increased, communities adaptive capacity enhanced, knowledge and attitudes improved and a sense of ocean stewardship, ownership and pride being restored back into communities. LMMAs have also transformed decision making for customary marine areas from a more traditional, autocratic style to a more participatory and democratic process of governance. In addition, social learning motivated by the CBAM approach is clearly evident in the adaptive measures implemented by communities and in policies and legislation put in place by provinces and the national government. In conclusion, the Fiji study revealed that LMMAs leads to improvement in the livelihoods of the people in all sorts of ways, both anticipated and unanticipated.

18A Evaluating management success
Monday 9 July, 1245, Hall B

What's in a name? Labels and management success

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Would a compelling name improve marine protected area management success? In the information era and a world of social media, getting conservation messages through the information noise presents new challenges. Commerce and industry have long recognized the value of brand names in selling products and customer loyalty. Not unlike industry, protected area managers rely upon awareness

in a large part for legal compliance (purchasing) and public support (loyalty) for their programs. Laws that provide strong protections are one important tool for conservation management success, but awareness of laws and MPA recognition are important factors for compliance and enforcement. Managers may choose to focus limited funding on management and enforcement, potentially to the detriment of conservation management. But, has 'branding' become a more effective management tool than strong conservation laws? The United States remote Pacific islands offer insight into naming and perceptions of conservation management. A history of governmental coral reef protections began more than 100 years ago by President Theodore Roosevelt and continued through the 1900s up to 2009 designations of marine national monuments. A veritable stew of management is named such things as wildlife refuges, marine national monuments, preserves, reserves, sanctuary, and Ramsar and World Heritage sites; with differing levels of protections corresponding to multiple IUCN protected area classifications. The interplay of authorities and the names attached to protections may both help and hinder conservation success of reefs. This case study examines nuisances of naming, public awareness and understanding, and varying challenges for conservation management success.

18A Evaluating management success
Tuesday 10 July, 1035, Hall B

Advancing expert judgments of ecosystem condition

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Ecosystem protection goals are increasingly the foundation of conservation policies worldwide. Assessments of ecosystem condition are thus increasingly used to support evaluation of management effectiveness. However, direct measurements of ecosystem condition are beyond the reach of current science. Managers are therefore relying on expert judgments in which a diverse group of experts is asked to consider a broad range of scientific data and results and use this information to develop a condition assessment. Currently, despite some common theoretical underpinning, there is no clear framework for such processes. Applications have relied to differing degrees on scientific analyses, and different processes for reaching a consensus assessment. The lack of consistency of approach renders the tool of expert judgment, and the judgments themselves, vulnerable to attack and dismissal merely as 'opinion'. This jeopardizes the use of this essential tool - and the underlying science - just as the needed transition to ecosystem-based management approaches is gaining momentum globally. Using data from kelp forest and rocky intertidal ecosystems in California and the Great Barrier Reef, we are implementing an expert judgment process designed to provide assessments of the condition or 'health' of these regional ecosystems. Through this process we are developing standards, guidelines, and a rigorous theoretical framework, thus establishing good practice for such assessments, making them more legitimate and more likely to have appropriate impact on decision-making. Moreover, we are identifying the information used by experts in these processes, allowing resource-limited monitoring programs to prioritize collection of the most useful ecosystem metrics.

18A Evaluating management success
Monday 9 July, 1040, Hall B

18B Managing coral reef ecosystems under a changing climate

Conservation objectives under climate change

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Spatial and temporal dynamics are important in marine systems, but climate change makes their consideration in marine protected area design even more critical. Developing specific conservation objectives for variability will be important for incorporating dynamics into conservation planning. We analysed sea surface temperature (SST) trends in Great Barrier Reef Marine Park (GBRMP), and formulated and tested three sets of notional conservation objectives to illustrate the potential for planning to address climate change. Given mixed and limited evidence that no-take areas increase resilience to disturbances such as anomalously high temperatures, we focus our conservation objectives on areas less likely to be affected by such events at scales ranging from the whole Great Barrier Reef, to the system of no-take zones and individual no-take zones: (1) at least 50% of temperature refugia should be captured within no-take zones, here defined in two ways - as pixels that contain anomalously high temperatures (>1°C above monthly mean climatology) less than 4%, and less than 6%, of the time; (2) maximum occurrence of high temperature anomalies should be less than 10%, 20%, or 30% of total no-take area 90% of the time; and (3) complete coverage of any single no-take zone by high temperature anomalies should occur less than 5% or 10% of the time. We used satellite imagery from 1985-

2009. We found that SSTs in the Great Barrier Reef are increasing significantly in some regions, and some but not all of the notional conservation objectives were met by the GBRMP's current zoning plan.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1215, Hall B

Integrated reef health assessments enable responses to climate change impacts

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The Great Barrier Reef (GBR) is the world's largest and most iconic coral reef ecosystem. Since 1975, the GBR has been managed as a multiple use marine park that includes commercial tourism and fishing activities that contribute $5.4 billion to the Australian economy each year. Climate change threatens both the health of the GBR ecosystem and the industries and communities that rely upon it. Management actions, that maximise resilience by controlling local stressors, are widely cited as providing the best opportunity for climate adaptation. A dynamic understanding of the drivers and status of GBR health is essential to build ecosystem resilience. Reef health impacts may be synergistic and simultaneous, and can have legacies that last for many years (cumulative impacts). To effectively respond, resource managers need near real time, ecosystem scale, reef health status reports to inform management decisions. The vast size and challenging logistics presented by the GBR mean that this cannot be achieved by long-term monitoring programs alone. The solution to this problem is to build reef health assessment capacity amongst other reef users such as tourism operators, community volunteers and marine park rangers. To be successful, the reef health assessment methods need to be matched to the range of observer skills and able to deliver information that is comparable with long-term monitoring programs. We present an integrated approach that builds spatial and temporal coverage, rapid assessment tools and a framework for prioritising scalable responses to incidents that affect the health and resilience of the GBR

18B Managing coral reef ecosystems under a changing climate
Thursday 12 July, 0930, Hall B

Climate Change Action Plan for the Florida reef system

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Global climate change impacts - operating alone or in tandem with localized stresses - are primary causes of decline in Florida's coral reef system. Extending for 300 nautical miles along the state's southeast coast, these reefs are vital habitat for marine life from commercial fish to sea turtles. Each year, diving, fishing, and other reef-related activities generate 71,000 jobs and $6.3 billion in economic activity. The Climate Change Action Plan for the Florida Reef System 2010-2015 (Action Plan) was developed by reef managers, scientists and reef users involved in the Florida Reef Resilience Program as a guide for improving the health and sustainability of this national treasure. The Action Plan describes three general outcomes; 1) increased resilience to global climate change via active management of local reef impacts, 2) enhanced communications and awareness, and 3) targeted research. Each outcome is supported by specific objectives and each objective is designed to be achieved through the completion of discrete actions - forty in all - which may be implemented at the local level by reef managers and reef users. The Action Plan also describes six 'enabling conditions' (e.g. an international greenhouse gas emissions reduction agreement), which are essential for protection of the Florida reef system but are beyond local control. By promoting enabling conditions and taking local action now, responsible national, state and local governments and the people who depend upon Florida's reefs for their livelihoods or recreational pursuits can positively influence the future of this vital natural resource in the face of climate change.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1530, Hall B

Interactions between stressors and climate change in coral ecosystem management

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There is growing concern that interactions between impacts of climate change and other localised human threats, such as fishing and eutrophication, may increase the rate of coral reef ecosystem degradation. Causes of climate

change cannot be manipulated at regional scales, thus management could compensate for its negative impacts by reducing local stressors. Using a model of multiple stressor impacts on coral reefs, we investigate the direction and magnitude of changes in a local stressor required to compensate for negative climate change effects with synergistic and antagonistic interactions. For synergistic interactions, the combined effect of stressors is a greater decline in the ecosystem than the sum of their individual effects. Antagonistic interactions cause smaller declines or improvements of ecosystem state when compared to the sum of individual effects. Both types of interactions may be common. Counter-intuitively, analysis of global warming stress and nutrient input stress on coral reef ecosystems demonstrates that a synergistic interactions may be more straightforward to manage than an antagonistic interaction. An synergistic interaction requires smaller changes to the nutrient stressor than expected on the basis of individual effects. Further, management should always reduce the local stressor when there is a synergistic interaction. Whereas, for antagonistic interactions, the management response may change from reducing to increasing the local stressor with changes in the magnitude of stressor values. These results indicate that research will best advise management if there is a focus on indentifying interactive effects of climate change with local stressors.

18B Managing coral reef ecosystems under a changing climate
Thursday 12 July, 1000, Hall B

Managing coral reefs under climate change: the Florida experience

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Climate change has been the primary driver for the decline of the coral reef ecosystem of the Florida Keys for over 30 years. Consequently, the management response of coral reef managers and scientists has evolved over the decades, as the linkages between coral reef decline and climate-induced stressors have been identified. These stressors have been exacerbated by anthropogenic influences such as land-based sources of pollution, habitat destruction and overfishing. Advancements in monitoring methodologies from *in situ* observations and remote sensing techniques have contributed to an evolving management response. Satellite technology has advanced the predictability of local, regional and global perturbations driven by a changing climate. These techniques have been an essential nexus in the communication between coral reef scientists and managers and have opened the door to innovative solutions and adaptive management approaches. Among the most notable hurdles for coral reef managers and scientists alike was the scientific debate that took place throughout the 1980's and most of the 1990's as to whether or not climate change played a role in the decline of coral reef ecosystems. This loud and sometimes rancorous difference of opinion left the public confused and gave decision-makers a reason not to make decisions. However, the debate created a collaborative atmosphere among managers and scientists and developed new management approaches that are now shared and explored around the globe. As we look to the future, the tools we use as coral reef managers and scientists will be built on these lessons from the past.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1400, Hall B

Coral growth under thermal stress and shading in American Samoa

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I tested the hypothesis that shading at an early stage of cumulative thermal stress, as described by NOAA's Coral Reef Watch - Satellite Bleaching Alert System, can serve as a mitigating management strategy. I analyzed growth, under thermal stress and different levels of shading, of coral fragments harvested from various branching colonies of *Acropora muricata*, *Pocillopora damicornis* and *Porites cylindrica*, located at the National Park of American Samoa in Ofu. Approximately 30 coral fragments per species were placed in each of eight aquaria that received full natural sunlight, for a total of ca. 720 corals; 240 corals per species. There were two controls at ca. 28.5°C, and all other aquaria were kept at ca. 31.5°C; two had no shading, two had 50% shading starting at Degree Heating Week 1 and two had 75% shading starting at Degree Heating Week 1. The experiment was conducted in July-August 2011, and lasted for one month. Coral fragments had their buoyant weight measured at the beginning and at the end of the experiment. Control corals grew faster than corals under thermal stress, as expected. In thermally-stressed aquaria; *A. muricata* under both levels of shading did statistically better than corals in aquaria fully exposed to sunlight, *P. damicornis* grew more under 50% shade, and *P. cylindrica* under 75% shade. I concluded that shading is potentially an effective tool to reduce stress under prolonged high water temperature conditions, but that the level of shading necessary seems to vary by species.

18B Managing coral reef ecosystems under a changing climate
P190

Communication challenges for contentious science

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Those who know what is happening in ecosystems as a result of climate change need to be actively communicating about climate change risks to both the general public and decision makers. But traditional science communication tools do not work well when confronting those who 'don't get it', or are resistant to the messages, suggesting new ways of communicating need to be explored. Research into the reasons that the public reject many new technologies provides insights into why some members of the public reject the science of climate change, and provides some clarity for better tools and solutions to use in addressing the challenges of communicating climate change issues. These include: when information is complex, people make decisions based on their values and beliefs; people seek affirmation of their attitudes (or beliefs) - no matter how fringe - and will reject any information or facts that are counter to their attitudes (or beliefs); attitudes that were not formed by facts and logic are not well influenced by facts and logic; and people most trust those whose values mirror their own.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1700, Hall B

Long term monitoring for climate change impact in Jamaica

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The Caribbean Planning for Adaptation to Climate Change (CPACC) project was a regional programme established in the Caribbean in 1998 by CARICOM countries in response to the growing concerns regarding the impacts of climate change. Component 5 of this project - Coral Reef Monitoring for Climate Change Impacts - was implemented in three pilot countries, of which Jamaica was one, and was designed to establish a long term coral reef monitoring programme in the region. Despite challenges related to human and financial resources Jamaica was able to institutionalize the monitoring programme with field monitoring carried out by the National Environment and Planning Agency and data processing and analysis done by the Centre for Marine Sciences. Three Operational Areas were established (Eastern Portland, Discovery Bay and Port Royal) and monitored over the period 2000 to 2003 and 2007 to 2011 using the CPACC video monitoring protocol. This paper will present the results of this long term monitoring for climate change impacts for Discovery Bay on the north coast of Jamaica. Over the monitoring period the benthic substrate was dominated by macroalgae and dead coral with algae. Hard coral cover ranged from 6.7% (2000) to 11.74% (2010) with no significant declined observed, even after the major bleaching event in 2005. *Porites astreoides*, *Siderastrea siderea*, *Montastrea annularis* and *M. faveolata* were the most commonly occurring species during the monitoring period. This study represents the only long term monitoring programme to result from the CPACC project. Data analysis of the other two sites is ongoing.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1515, Hall B

Filling scientific knowledge gaps for marine park management: a review

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The GBRMPA's 2009 Great Barrier Reef Outlook Report concludes that the Great Barrier Reef ecosystem is at a crossroads, and it is the decisions made in the next few years that will determine its long-term future. The GBRMPA uses the best available science to underpin management. To achieve this, key knowledge gaps that limit management actions need to be identified and addressed. The 2007 GBRMPA document, Climate Change and the Great Barrier Reef: A vulnerability assessment, identified 100 key knowledge gaps, which were workshopped to determine their importance to management. Of these, 22 knowledge gaps were deemed 'critical' by GBRMPA and stakeholder workshop participants. Between 2007 and 2012, funding from the GBRMPA Climate Change Action Plan has been used to address all of these priority knowledge gaps to varying degrees through partnerships, direct investments and co-investments with university researchers, scientific institutions and management agencies. Areas of critical research investment included climate change impacts on marine ecosystem processes, and the vulnerability, resilience and adaptation potential of key ecosystem components. In addition, GBRMPA has directly invested in

research into impact mitigation and resilience building strategies, which guide adaptive management of the Great Barrier Reef under a changing climate. GBRMPA is currently working with researchers on a series of National Environmental Research Program projects that further our capacity to build the resilience of the Great Barrier Reef ecosystem. We present here a summary of the outcomes of this research investment and their importance for the future management of the Great Barrier Reef.

18B Managing coral reef ecosystems under a changing climate
P191

Scoping social limits to climate change adaptation in the Great Barrier Reef, Australia

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For improved reef management under climate change, it is important to understand limits to climate change adaptation, because they reflect the point at which an adaptation strategy fails to reduce vulnerability, or costs more than the averted impacts. In one of the first studies to empirically explore social limits to adaptation, we examined social limits to climate change adaptation in the Great Barrier Reef and its fishing and tourism industries. We developed a set of four alternative future scenarios for the Great Barrier Reef in conjunction with scientists working on climate change in Australia. We presented these scenarios to representatives of state and local governments, the fishing and tourism industries, non-governmental organisations, and scientific institutions to investigate experiences of adaptation, desirable outcomes from adaptation, and potential limits to adaptation in the region. We found that distinct adaptation strategies are influenced by a diversity of interacting limits, which are socially constructed and, therefore, often couched as future opportunities. We characterise these interacting limits into broad themes, which include: A whole industry perspective; Uncertainty and system connectivity; Private action for public goods; Perceptions and reputations, and; Australia in a globalised world. We discuss each group of limits and provide relevant examples from the Great Barrier Reef region. These themes provide potential entry points for integrated reef governance and we suggest ways in which this scoping study may be taken forward for future policy development.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1630, Hall B

Opportunities and challenges to manage marine mega-fauna in a changing climate

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Marine mega-fauna are key components of marine ecosystems that have social and economical value. Many populations of marine mega-fauna have declined largely due to anthropogenic threats. Further impacts to this important group will occur from predicted climate change affecting their distribution, behaviour, reproduction and demographics. The resilience of many populations of marine mega-fauna to climate change is severely compromised by dramatic reductions in population sizes and thus their ability to adapt and recover from climate change is reduced. Conservation strategies that help species moderate or cope with projected climate change are needed. However, dealing with the reality of climate change is challenging as incorporating actions to alleviate the impacts of climate change into ongoing conservation projects is often limited largely by uncertainties in what action can be taken. Thus, there is the need for new, flexible and dynamic conservation strategies that integrate climate impacts, species responses and changing ecological relationships. This presentation will focus on the systematic management of marine mega-fauna in a changing climate, using sea turtles as a case study. It will highlight the threats that sea turtles face as climate change progresses and potential management strategies. Twenty management strategies are identified; strategies vary from habitat protection to more active and direct manipulation of nests and the nesting environment. The effectiveness, ecological risks and potential social and logistical constraints associated with implementing each of the identified management strategies is discussed. Further, challenges and opportunities of incorporating threats of climate change to marine mega-fauna management will also be discussed.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1145, Hall B

Climate smart sanctuary: buildling resilient reefs in American Samoa

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Global and regional changes to the marine environment associated with climate change will have significant consequences for coral reef ecosystems, coastal communities, and maritime heritage resources relevant to the Fagatele Bay National Marine Sanctuary (FBNMS) in American Samoa. Regional physical changes to the marine environment include climate variability, sea level rise, ocean circulation patterns, and ocean acidification. These changes combined with anthropogenic stressors may produce cumulative impacts on biodiversity and ecosystem health including changes in physiology, phenology, and population connectivity, and species range shift. This paper identifies and synthesizes potential climate change impacts in American Samoa and the region over the next fifty years. This information will help inform priority management actions for the Sanctuary to take to respond to the impacts of climate change on natural systems and human activities within American Samoa. The paper was written as a component of the Climate Smart Sanctuary process developed by the National Oceanic and Atmospheric Administration (NOAA) to help national marine sanctuaries and other marine protected areas plan for, adapt to, and manage for impacts associated with climate change. Its components include a process for developing a climate change site scenario and climate change action plan; obtaining advisory council and other public input; conducting training for staff and partners; greening operations; and preparing documentation for and obtaining certification. Fagatele Bay National Marine Sanctuary seeks to become the first marine protected area in the United States to be certified as a Climate-Smart Sanctuary.

18B Managing coral reef ecosystems under a changing climate
P192

How can the climate change crisis inspire behaviour change?

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Creating and communicating solutions for the management of natural resources is critical to the process of effectively responding to climate change. Successful communication strategies can assist in gaining public support for legislation, conservation initiatives, and policies aimed at addressing the impacts of climate change. Numerous ongoing and often expensive efforts are currently being implemented to educate the public about climate change and to encourage low-carbon lifestyles. Although several studies have found high levels of public awareness related to climate change, they also document little corresponding behavioural response. Information alone is not sufficient to change behaviour. However, communication strategies based on psychographic variables, such as social, economic, cognitive, and emotional drivers of change, can be effective tools for altering individual behaviour related to climate change. A vital consideration for these communication outputs is how to design messages for different audiences that facilitate rather than constrain action, and minimise barriers while simultaneously enhancing the benefits of taking action. Communication strategies that are tailored to specific population segments and which stress personal relevance and achievable effective responses may be more effective than a one-size-fits-all approach which fails to distinguish between different social positions and constraints to action. A case study of Great Barrier Reef user groups seeks to identify how and why messages produce different emotional, moral and behavioural responses. Advances in social marketing, communication and messaging will allow policy makers and resource managers to communicate the need for behavioural change in response to climate change in a more meaningful and relevant way.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1745, Hall B

Novel genomic tools and the management of coral reefs

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The application of genetic tools in natural resource management remains sparse despite their potent and increasingly feasible utility. This talk will introduce aspects of coral reef management that can benefit from the use of genetic data and genetic tools. It will give examples of how genetics can be used to predict realised dispersal distance of species and how genetic markers can be used to improve predictions regarding adaptive potential, determine the relative stress tolerance of individuals and populations and thus identify reefs that harbour populations of corals with higher stress tolerance. In the not too distant future, managers of coral reefs may have to start facing the possibility of employing genetic tools that are currently restricted to commercial species, such as selective breeding for increased stress tolerance, cryo preservation of gametes of tolerant genotypes in seed banks and targeted coral husbandry for the sake of restoring and preserving key reefs and key coral species. It is therefore important that we increase our understanding of the underlying molecular mechanisms of stress tolerance to ensure the benefits are larger than the risks involved.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1645, Hall B

Dive tourism professionals as climate change early warning and communications

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Climate change represents the most significant global threat to coral reefs. Local management responses to build reef resilience to climate change that employ planning and conservation interventions targeted solely at conventional resource management audiences (MPA managers, NGOs, academics) are a critical first step, but ultimately lack sufficient scale and broad communication potential to catalyze meaningful progress towards resilience. Adapting resources originally developed by The Nature Conservancy and NOAA Coral Reef Watch, the Coral Reef Alliance has piloted a promising new application of the reef resilience to climate change curriculum to target a non-traditional audience of dive tourism professionals in coral reef destinations throughout the Caribbean Basin as an early response and communications team. Dive tourism professionals far outnumber management professionals, spend more time observing reefs than reef resource managers, and have been shown to be capable of detecting changes on reefs before they can be scientifically demonstrated. Through training in principles of coral reef ecology, climate change impacts to reefs (bleaching, coral disease, etc), basic reef monitoring protocol, and online remote sensing and prediction tools, dive tourism operators are empowered to assist resource managers as an on-site early warning system of reef impacts from climate change. Importantly, dive tourism professionals also represents an opportunity to communicate reef threats to visiting tourists as well as tourism associations and tourism ministries to underscore threats to tourism economies from climate change. This session highlights successes observed in piloting this approach thus far as well as challenges yet to be overcome in rapidly scaling-up.

18B Managing coral reef ecosystems under a changing climate
Thursday 12 July, 1040, Hall B

Building ecosystem resilience through spatial planning in Thailand's Andaman Sea

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The Andaman Sea of Thailand experienced unprecedented mass coral bleaching with very high mortality rates in 2010. Post-bleaching surveys showed that the bleaching impact was not uniform and differed both at regional and local scales. Twenty-five indicators were identified through a participatory workshop with local experts to assess coral reef resilience at over 220 survey stations across the region. Long-term quantitative data collected by Phuket Marine Biological Center and semi-quantitative method were employed to assess and determine resilient reef areas both inside and outside Marine Protected Areas (MPAs). Resilience indicators and sea surface temperature trends since 1985 were mapped spatially to review the current MPA system and assess whether or not it is located appropriately and well planned to withstand conditions that are going to become more prevalent under future climate change regimes. Areas of greater resilience outside MPAs were identified as priorities for conservation and will serve as key stepping stones in developing a more resilient MPA network. Critical habitats such as mangrove and seagrass beds were also considered in MPA network design to enhance coral recovery and improve connectivity. In addition, this paper suggests key actions toward more integrative monitoring and management, and provides a

conservation-based platform for long-term marine spatial planning in the Andaman bioregion.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1445, Hall B

Identifying coral 'refugia' in Keppel Bay through bathymetry and habitat assessment.

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The Keppel Islands is a unique system of inshore fringing reefs on the coast of Central Queensland that is relatively geographically isolated from the rest of the Great Barrier Reef. Reefs in this region have high coral cover, rich and diverse species composition, and strong regeneration capacity, and appear highly resilient to disturbance. They are also important to the local community for tourism and recreation. In spite of their apparent strong and rapid recovery following a bleaching event in 2006 and moderate flooding in 2008 and 2010, there is still concern about their capacity for resilience in the face of more frequent disturbance as they are highly vulnerable to the influence of the adjacent Fitzroy catchment and bleaching. For instance, flooding caused extensive mortality in 1991 and 2011 and bleaching caused moderate mortality in 2006. Bathymetry studies and post- 2011 flood Reef Health and Impact Surveys were combined with the results of previous coral species composition mapping to investigate the concept of the existence of coral 'refuges' in the Keppels. 'Refugia' are pockets of highly diverse coral communities that may be relatively immune to catastrophic disturbance by nature of their geographic location, depth and species richness and composition. Mortality from floods, storms and bleaching is more likely to occur on shallow reefs close to shores therefore refugia are likely to be found at deeper sites. This study combines research conducted by the QPWS and AIMS and CQU to investigate the post-flood status of suspected coral refuges in the Keppels.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1730, Hall B

Building social-ecological resilience: the adaptation of coral reef management

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The high vulnerability of coral reefs to climate change puts reef scientists and managers at the frontier of climate change adaptation. Over the last decade we have developed an enviable understanding of the risks posed by climate change, driving broad consensus that coral reef systems face unprecedented challenges. While inertia in social and climate systems commits coral reefs to further degradation, successful adaptation can help avoid the most serious and potentially irreversible impacts. However, we have to move beyond business-as-usual. We need to realise that conventional conservation objectives are decreasingly relevant: we have to shift toward a paradigm that explicitly integrates biodiversity protection and livelihood outcomes, embraces non-equilibrium, non-linear system dynamics, accepts the validity of active interventions and shares in the responsibility for influencing climate policy. Resilience is being widely adopted as a conceptual framework to drive the adaptation of management approaches, and we are now making important progress toward operationalising key resilience concepts. Under the Great Barrier Reef Climate Change Action Plan we have collaborated with scientists and managers from around the world to develop resilience metrics using community participation and are building a vulnerability mapping system to support marine spatial planning. We have developed and applied a framework for integrating social and ecological vulnerability assessments, and successfully advanced adaptation planning with three commercial fishing industries. We are also breaking down policy barriers through adaptive management plans for climate-sensitive biodiversity hotspots. This presentation will review these and other advances in efforts at building social-ecological resilience in coral reef systems.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1115, Hall B

Raine Island : the logistical challenges of remote island management

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Queensland and Australian Government agencies have identified management actions to improve the resilience of threatened green turtle and seabird reproduction at Raine Island. Raine Island (the most important breeding site on the GBR for green turtles) is located on the far north eastern edge of the reef and over 750 km from the nearest major management base.

This makes even basic management efforts difficult and expensive with seasonal weather conditions, high logistical costs and staff availability all impacting on management capacity. For these reasons prioritised management actions have included the development and testing of remote sensing capability to gather real time data on daily climatic conditions, sea levels and temperatures (including tidal inundation), seabird nesting and turtle movements (including reproductive activity). Other works are also being trialled that will enable unattended ongoing management action (e.g. fence structures to keep adult nesting turtles from high risk areas). Key to this project is its capacity to be adaptive. While the major threats to turtles and seabirds at the island have been identified, significant knowledge gaps remain. The project is being implemented in a way that will result in the collection of key data at the same time as trialling management actions to improve the islands capacity as a sea turtle and seabird rookery under changing climatic conditions. This presentation will outline the achievements of the projects implementation so far; lessons learned and proposed future actions at the island will be discussed.

18B Managing coral reef ecosystems under a changing climate
P193

Evolving coral reef management under climate change: the GBR experience

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The Great Barrier Reef Marine Park was established in 1975 for the long term protection and conservation of the Great Barrier Reef. In pursuing this objective, the Great Barrier Reef Marine Park Authority pioneered many of the approaches to coral reef management that are now standard practice. Recent initiatives continue to advance reef conservation, including the Reef Water Quality Protection Plan, major revisions to fishing arrangements and an increase in no-take zones from 5 to 33% of the Marine Park. Despite these initiatives, recent data indicate significant decline in ecosystem health indicators over the past 20 years. Combined with the mounting pressures from climate change, these observations have lead to an official outlook for the Reef that is poor. Through rising sea temperatures, ocean acidification and increased storm intensity climate change is dramatically altering the disturbance regime of coral reefs while also exacerbating the threat from more conventional stressors like pollution, coastal development, fishing and increasing use. It is clear that coral reefs are facing unprecedented risk. In this presentation we will share some of the ways we are adapting the management of the Great Barrier Reef to tackle these cumulative stresses. Key strategies include forging new partnerships with commercial fishers to improve economic and ecological sustainability; building stewardship to increase grass-roots participation in reef conservation; extending management effort beyond no-take areas; working with land managers to reduce land-based sources of pollution; improving our understanding of stressor interactions; and developing approaches to tackle the complexity of coastal zone management issues.

18B Managing coral reef ecosystems under a changing climate
Thursday 12 July, 0945, Hall B

Preparing to manage coral reefs for ocean acidification: lessons from coral bleaching

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The increasing atmospheric concentration of carbon dioxide is changing the carbonate chemistry of ocean surface waters, a process known as ocean acidification (OA). OA is predicted to have significant impacts on marine ecosystems and species, yet the responses to changing seawater carbonate chemistry appear to vary with species and perhaps across habitats, suggesting that some areas may be more resistant to OA. If OA impacts follow predictable spatial patterns, then conservation managers will be able to incorporate OA into their conservation and planning strategies. To date, little emphasis has been placed on developing conservation strategies that address OA. By building on lessons developed to address coral bleaching, we outline how managers can begin to address this gap. MPA design principles that address coral bleaching are well established. These principles include: 1) protecting key refuges (e.g., areas that naturally resist or recover from bleaching); 2) protecting replicates of major habitat types to reduce the chances they will all be affected by the same disturbance; 3) maintaining

ecological connectivity among MPAs; and 4) prioritizing areas where ecosystem resilience can be enhanced through effective management of local stressors. This presentation highlights recent advances that allow us to refine these principles to address OA, and presents research priorities to further inform MPA planning and management. Research priorities include: establishing an ocean carbon chemistry and ecological baseline, determining species / habitat / community sensitivity to OA, projecting changes in seawater carbonate chemistry, and identifying potential synergistic effects of multiple stressors.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1200, Hall B

Using effective communication tools to foster stewardship and adaptation

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Stewardship is built through engagement and relies on reaching relevant stakeholders through effective communication. A vital first step is ensuring the necessary information exists which can later be used to develop targeted communications. One of the tools used by the Great Barrier Reef Marine Park Authority (GBRMPA) to fill knowledge gaps is an awards scheme that supports early career marine scientists in their climate change research. It is also important to understand current community beliefs and opinions towards climate change and the Reef when developing communications strategies around these topics. The GBRMPA has conducted phone surveys over multiple years to provide insights that helped inform climate change communication activities and improve the effectiveness of its messaging. Both responsive and proactive communication materials are necessary to raise awareness regarding the health and future of the Reef. To engage further with stakeholders, the GBRMPA has also supported local and national events. Regional efforts have included the development of educational climate change signage for Commonwealth Islands as well as initiatives developed by Local Marine Advisory Committees. Awareness raising facts sheets and posters have been developed for Reef-reliant industry staff and their customers. Communication with international audiences has been accomplished through a series of climate change animations and publications such as project bulletins which have been delivered through the GBRMPA corporate website. Together the GBRMPA's comprehensive suite of communications products target key knowledge outcomes from the Climate Change Action Plan to motivate adaptation and stewardship amongst Reef stakeholders.

18B Managing coral reef ecosystems under a changing climate
P194

Working together to achieve change

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Change is fundamental to reef socio-ecological systems. Climate change provides real incentive to be proactive about it and look to collective futures for the coral reef environment, managers and industries. Change requires willingness, energy and a spirit of collaboration: to take the blinkers off; to establish what you already have and to understand your operating environment and explore what it may become. This is the only way to gain an understanding of what adaptation may be required to prepare for anticipated futures. Importantly, it is not only industry that needs to be prepared to think outside the square. Management must equally - because business, and the thinking around it, will not be 'as usual'. We will share our experience working with a progressive fishery in the Great Barrier Reef Marine Park. We say progressive, because it is. Poor public perception coupled with ignorance of what the aquarium supply fishery actually does nearly shut it down. It met those challenges head on drawing both Marine Park and Fisheries Managers together in a productive collaboration. Collectively we learned. The fishery examined its vulnerabilities and produced a rigorous vulnerability assessment. It then went further and produced a Stewardship Action Plan (SAP) that dovetailed with the Queensland Coral Stress Response Plan and the GBRMPA's Coral Bleaching Response Plan. The SAP was activated (possibly a first for a fishery anywhere) in response to the extreme weather events of 2011. Learnings are being incorporated into the SAP and climate change adaptation planning for the fishery.

18B Managing coral reef ecosystems under a changing climate
Thursday 12 July, 1030, Hall B

Climate change adaptation planning in practice with an Australian fishery

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Climate change poses substantial challenges for industries dependent on reef ecosystems. This presentation focuses on experience and learning from a novel application of climate change adaptation planning through engagement with an Australian fishery. The case study is for the Queensland East Coast Otter Trawl Fishery. The work began with a robust re-examination of risks from trawling activities to the Great Barrier Reef ecosystem. Ecological risk assessment findings fed into an assessment of the ecological vulnerability of the fishery to climate change. The project team then worked with stakeholders to apply a risk management tool called the Climate Risk Management Matrix. For this, we used a process of small group discussion, and held a series of expert and regional workshops. The completed matrix indentifies climate change interactions, possible adaptation responses and vulnerabilities for the fishery. We found engaging stakeholders in risk management exercises was a valuable approach for taking adaptation planning from theory to practice. The regional workshops allowed participants to discuss impacts and adaptations within realistic contexts. The tools used were valuable for capturing and analysing both biophysical and socio-economic aspects, and considering these in light of other pressures on the industry. Participant feedback indicated the approach, particularly the workshop series and small group discussions, was effective for considering climate change impacts and needs of the fishery. We now have an improved understanding of climate vulnerability for the fishery. Work is ongoing to incorporate climate mitigation and adaptation thinking into management, business planning and operations.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1230, Hall B

Climate change predictions as a key component of a green turtle population model

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The green turtle stock that nests at islands and cays in the Northern Great Barrier Reef (NGBR) is one of the largest in the world. This stock is under pressure from a diverse array of anthropogenic activities and there is evidence to suggest that this stock is in the early stages of decline and pro-active management is needed to stabilise this globally significant population. A population model has been developed for this green turtle stock to: i) aid in effective management decisions based on the model output under different harvest strategies or other levels of mortality, and with different climatic scenarios; ii) promote the conservation of turtle stocks through informed decisions; and iii) use the visual output of the model to educate and raise awareness among Indigenous communities and other interested parties. Within the main population model three sub-models were developed to allow managers and researchers to explore the impact of different management actions under various scenarios of climate change, including the ability to factor in the impacts of catastrophic events like cyclones on hatchling production. The most likely impact of climate change on green turtles will be sea-level rise causing erosion and increased inundation of nesting grounds and increasing sand temperatures skewing the sex ratio of hatchlings and contributing to a decrease in hatching success. Thus, it is necessary to incorporate the climatic data sets into this population model and test these predictions.

18B Managing coral reef ecosystems under a changing climate
P195

Storms, recovery, and protection: long term monitoring tells the story

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Since 2006, the Wildlife Conservation Society's (WCS) Papua New Guinea (PNG) Marine Program has monitored coral reefs in New Ireland Province that are under various forms

of management in order to contribute to improved marine management at the local level. Most of WCS partner communities use a traditional form of management, tambu areas, to restrict fishing within their small customarily-owned areas. In early December 2008, a combination of high spring tides and very large swells from distant storms resulted in a disastrous 'King Tide' event in the province. The tidal surge inundated coastal communities, destroyed homes, washed out burial grounds, overturned corals, and decimated marine habitats along the exposed east coast. The event severely affected the marine environment of four of the WCS partner communities. Both tambu and fished areas that WCS monitors annually were similarly impacted: 2009 and 2010 data revealed that coral cover and fish diversity had declined dramatically in all areas and algae cover had increased through the colonization of newly available substrate. Data collected during late 2011 illustrates the continued ecological shifts since the event. Although this surge was not necessarily related to climate change, its impacts are similar to those anticipated from a changing climate, namely damage from increased storm frequency and salt water inundation. Coastal communities throughout the region are justifiably concerned about the impacts of climate change. Long-term monitoring programs allow us to identify the impacts of unexpected events and inform whether tambu areas help reefs maintain ecosystem functions and hasten recovery.

18B Managing coral reef ecosystems under a changing climate
Thursday 12 July, 1035, Hall B

Using the vulnerability assessment framework to develop a biodiversity strategy for the Great Barrier Reef

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To provide the best possible chance for conserving species, habitats and ecosystems of the Great Barrier Reef in a rapidly changing climate, it is essential that managers have the ability to both identify what we need to do differently in the future, as well as which existing strategies and activities continue to make sense from a climate adaptation perspective. It is also critical that we have an understanding of what other pressures are acting on the species and habitats so these impacts can be managed to minimise risks and enhance resilience. Vulnerability assessments are a key tool for informing adaptation planning and enabling resource managers to make such judgements. To aid and inform the development of the Great Barrier Reef Biodiversity Strategy 2011, vulnerability assessments were completed on habitats, species and groups of species that were listed protected species or identified from a range of past assessment processes as being most at risk. These vulnerability assessments were used to identify key sources of vulnerability; to identify appropriate and practical management actions that could be taken to mitigate risks and enhance ecosystem resilience; to identify gaps in management effectiveness, including deficiencies in legislation and policy, and those areas where additional research is required for making informed decisions. The vulnerability assessments were then used to inform the development of priorities for action in the Biodiversity Strategy.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1245, Hall B

Managing multiple use of the Great Barrier Reef: a paradigm shift?

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Management of the Great Barrier Reef Marine Park has evolved in the thirty years since its inception. The most significant change has been the shift to combat externally derived risks. Whereas early management was focused on spatial planning and mitigation of impacts from direct use, externally derived stressors such as land sourced runoff, coastal development and climate change are now a major focus of management attention. Where to from here in the face of a changing climate? While the focus must remain on the key stressors, a more active and vigorous approach to management in the Marine Park itself is emerging as the pressure from increased sea temperatures and other climate impacts increases. This involves more environmental manipulation at a local scale, fine scale adjustment by industry and other users, as well as stronger and smarter compliance measures to ensure the benefits of the Marine Park no take zones are realized. Examples include: manipulation of key turtle nesting habitat; measures to combat bleaching at individual tourism sites; greater control of crown of thorns starfish; greater requirement for rehabilitation of damage caused by accidents; and the use of offsets to compensate for unavoidable impact. These changes could be considered a paradigm shift toward levels of environmental intervention and manipulation usually associated with terrestrial environments.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1130, Hall B

Extreme weather adaptation options are location specific for commercial fisheries

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Extreme weather events, including intense tropical cyclones, are predicted to increase in frequency under climate change. Tropical cyclones have significant implications not just for coral reef ecosystems but also for the industries that depend upon them. Fisheries are an important part of coral reef socio-ecological systems, and are predicted to be impacted by climate change. To ensure ongoing sustainability of coral reef fisheries within a changing climate, managers need to understand the vulnerabilities of fisheries, explore their inherent adaptive capacity, and identify strategies and opportunities to enhance the capacity of the industries to adapt to change. More resilient fishers are more likely to ensure resilience of the entire socio-ecological system. Two recent category 5 cyclones on the Great Barrier Reef provided a valuable opportunity to explore adaptation options and limitations for Queensland commercial fisheries. Cyclone Hamish (March 2009) tracked neatly along the southern Great Barrier Reef, significantly affecting productivity of the high value but highly specialised reef line fishery. Cyclone Yasi (February 2011), traversed across the northern Great Barrier Reef affecting all fisheries within the region. Due to the different direction of the cyclone paths and structures of the fishing businesses in each of the affected regions, each cyclone presented different challenges and opportunities for adaptation. There were some commonalities, however; the main impacts were indirect, occurring throughout an extended lag period post-event, and some individuals have a much greater capacity to adapt than others. This work has revealed valuable insights for adaptation planning.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1415, Hall B

Raine Island: a climate change refuge for turtles and seabirds

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Green turtles and seabirds are at risk of climate change impacts and Raine Island is their most important breeding island in the Great Barrier Reef World Heritage Area. On Raine Island, seabird breeding numbers have declined and flooding has compromised turtle nesting success. The 'Climate Change Adaptation Planning' framework was used to identify and implement management actions to support Raine Island as a reproduction refuge for its inhabitants as the climate changes. Key steps were undertaken beginning with a 'Vulnerability Assessment', which evaluated the 'Exposure' and 'Sensitivity' of the fauna and their habitats to the threats of climate change to derive the 'Potential Impact'. The 'Adaptive Capacity' of the biota and the island cay was also assessed to determine their vulnerability. 'Resilience Analysis' was used to identify and evaluate the feasibility and risk of potential management interventions aimed at enhancing the reproductive resilience of vulnerable turtles and seabirds. The completed Resilience Analysis guided the development of an 'Adaptation Plan' to prioritise research and management actions. The Adaptation Planning process also included a review of current policy arrangements and their capacity to enable adaptive management. An 'Implementation Plan' was developed to detail the timing, capacity and logistics required to deliver on-ground works and the monitoring required to measure success. This presentation outlines the development of the Raine Island adaptation planning process and the results of the 2011 adaptation actions (including structural barriers, fencing and remote monitoring) aimed at reducing turtle mortality and improving turtle and seabird nesting success.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1430, Hall B

Working together today for a healthier reef tomorrow

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While our Great Barrier Reef continues to be recognised as one of the world's healthiest coral reef ecosystems; it's no surprise that climate change impacts dominate predictions about its future health. With limited regulatory and legislative influence over activities which drive environmental impacts on the Reef; the GBRMPA recognized that a hands-on approach at a community level was essential to help address these issues and preserve the Reef's immense social, economic and environmental value. This community based collaboration is a crucial element in securing a

healthier future for the Great Barrier Reef. Individuals and organisations that use and enjoy the Reef are demonstrating their commitment and taking practical steps every day to help safeguard its future. The Great Barrier Reef Marine Park Authority's Reef Guardian program demonstrates the effectiveness of building these relationships and the value of sharing responsibility for these desired environmental outcomes. The program encourages the sharing of information as a platform for the voluntary uptake of practices to improve the economic and environmental sustainability of the industries and community sectors involved and the health of the Reef itself. The community-based Reef Guardian stewardship programs are playing a critical role in ensuring the Reef is well placed to meet the challenges ahead. This presentation highlights the successes and challenges of the Reef Guardian stewardship program since its inception; it showcases the journey of developing the program and demonstrates how we are all working together today for a healthier reef tomorrow, in the face of a changing climate.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1715, Hall B

Building the resilience of the world's largest coral reef ecosystem

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Two of the most important strategies used to manage the Great Barrier Reef Marine Park are Zoning Plans to protect biodiversity from activities, particularly fishing, and the Reef Water Quality Protection Plan, the objective which aims to reverse the decline in water quality through improved land use management. The original intent of both strategies was not related to climate change, but to ecosystem health and resilience more generally. However, over the last decade it has become increasingly apparent that the success of these management tools is also critical to the Reef ecosystem's resilience to the impacts of climate change. After a decade of extreme weather events that have cumulatively caused significant damage to many major components of the ecosystem including coral reef benthos, seagrasses, dugongs and green turtles, there remains a significant challenge for Marine Park managers and their partners to improve existing strategies, and develop new ones, to maximise ecosystem resilience to future anticipated impacts of climate change. Using a resilience based approach, we have successfully implemented new no-anchoring areas at small scales and thereby improved reef recovery from impacts such as coral bleaching. We are exploring ways of quantifying and mapping ecosystem resilience and vulnerability to climate change impacts, so that future Marine Park management strategies can explicitly consider these. We are also exploring more direct intervention strategies such as restoration of damaged habitats. The future for the Great Barrier Reef remains uncertain with both local adaptation strategies and global mitigation efforts critical to securing that future.

18B Managing coral reef ecosystems under a changing climate
Thursday 12 July, 1015, Hall B

Developments in understanding relationships between environmental conditions and coral disease

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Coral disease events are emerging as a significant threat to coral reefs in a changing climate. Over the past few years, several modelling studies have derived empirical relationships linking white syndrome (WS) disease outbreaks on Pacific coral reefs with unusual temperatures in summer and winter, and host density. These relationships have informed development of a series of predictive tools - maps of outbreak likelihood for Australia's Great Barrier Reef and the Hawaiian archipelago. These tools are key to strategic regional frameworks to respond to coral disease outbreaks. They inform both the targeted monitoring that can improve our understanding of coral disease dynamics and trials of experimental management actions that may mitigate disease impacts. Early research suggests that water quality could be another key driver of coral disease prevalence on reefs, as poor water quality has been correlated with increased susceptibility of corals to diseases and bleaching. Therefore we plan to test the inclusion of water quality measurements as a means of increasing the predictive capacity of these management-directed tools. By reducing the number of false positives and negatives, we aim to refine and improve the accuracy of tools developed to assess disease outbreak

likelihood. Ongoing and future work also includes testing for links between environmental parameters and other coral diseases; expanding this work spatially, including a specific focus on coral disease dynamics in the Caribbean; and combining the learned relationships with climate predictions to examine potential future disease scenarios.

18B Managing coral reef ecosystems under a changing climate
P238

Mapping the resilience of Caribbean coral reefs

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Many Caribbean reefs exist in a relatively degraded state with low coral cover. A primary concern over such unhealthy reefs is that vital ecosystem services, such as the provision of fish habitat, will decline. Recent evidence suggests that Caribbean reefs may exhibit two alternate states such that reefs can get locked into a low-coral situation that are maintained by sustained recruitment failure of corals. We map the probability that reefs will become stuck in a coral-depleted state within a defined period of time (25 years), both with and without a marine reserve effect (fish grazing). Including a reserve increased the resilience (decreased probability of becoming stuck) of approximately one third of the examined reefs in Belize. We demonstrate our approach, which uses GIS and modeling to integrate information on the present ecosystem state, local ecosystem dynamics and predicted disturbance regime. Incorporated data layers include biological field data (coral and macroalgal cover, parrotfish biomass), wave exposure, hurricane frequency and intensity, observed satellite SST and modeled future SST. The application of our resilience mapping as a tool for marine spatial planning will also be discussed.

18B Managing coral reef ecosystems under a changing climate
Wednesday 11 July, 1500, Hall B

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation coral reef conservation

Integrating reef resilience into marine conservation and spatial planning

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Mapping the resilience of coral reef systems to climate change and other local-to-global human threats can provide essential guidance when addressing inevitable change and minimizing losses of biodiversity and ecosystem services. We examine the potential utility of site-level, spatially explicit, field data collected over large areas to visualize resilience patterns and inform systematic spatial planning for protection and management. The main question asked was whether a resilience map can be developed using these data and how different management strategies can be formally and consistently selected taking into account the relative resilience of different reefs. Two main regions, the Red Sea and East Africa, were used to develop this methodology. The main types of data used include base maps with reef locations, SST and chlorophyll concentration maps, ecological resilience data, and geo-referenced social information. A methodology for integrating spatially explicit resilience data into systematic planning is presented and initial resilience maps, their strengths and weaknesses for developing management strategies, are discussed.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Wednesday 11 July, 1015, Hall B

Conservation and management using habitat maps: lessons from 10 studies

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In the past 10 years, we have used habitat maps developed with remote sensing data in 10 different coral reef projects worldwide. Maps were used at different scales for fishery management, biodiversity census, Marine Protected Area design, surrogacy analysis, ecoregional analysis, gap analysis and climate change vulnerability assessment. Practical lessons from these 10 projects are presented. In contrast to the most recent scientific literature that suggests that approaches of ever increasing complexity are needed, we show that managers still first need extremely basic information to be able to make significant progress in their tasks: thematically rich, optimized and accurate habitat maps and typologies, habitat-based monitoring strategy, habitat-based selection of conservation sites, habitat-based fishery stock assessment, and

products for communication to stakeholders remain the top-5 best-sellers for spatial analysts. In the few areas where these basics are secured and where different temporal, spatial, ecological and governance components need to be integrated, more advanced activities become priorities, such as understanding the cost-effectiveness of spatial data acquisition, conducting sensitivity analysis, integrating biological and ecological processes, developing new communication tools to the larger public, and supporting the coordination of top-down vs bottom-up management approaches. We show for the 10 case studies the level of progress achieved at these two different basic and advanced steps of spatial data integration. We emphasize which significant gaps exist in terms of integration of ecological processes, what could be generalized from one site to another, and what was ultimately useful for managers.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1115, Hall B

Spatio-temporal distribution of human use at Ningaloo Reef, Australia

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Understanding where, when, and how many people use reefs is imperative for their conservation and management. A multi-disciplinary study, using geo-referenced aerial and coastal surveys along the length of Ningaloo Reef combined with 1200 visitor interviews, enabled spatio-temporal patterns in boat-based and coastal recreational activities to be determined. The use of Ningaloo Reef is markedly seasonal with a clear increase in the number of people, and expansion of their spatial extent, during the austral winter. Many recreational activities, including fishing, snorkelling, surfing, wild-life interaction (whale sharks and manta rays), relaxing on the beach and camping along the coast, take place at Ningaloo Reef. The relationship between types of recreational activity and spatial zoning of Ningaloo Marine Park was significant, with strong association between snorkelling and sanctuary zones. Although fishing generally took place in recreation zones, the spatially-explicit nature of the study also enabled estimates of compliance with sanctuary zones to be made. Travel network analysis on utilization of coastal roads, tracks and boat launching areas adjacent to the reef highlighted node-based patterns of use as well as rapid decay with distance from access points. The results of this multi-disciplinary study are appropriate and well-suited to coral reef conservation, in particular, for systematic conservation planning. They also provide a robust bench mark and readily measurable indicators for ongoing monitoring, management and management strategy evaluation at Ningaloo Reef. The protocols developed during this study are readily transferable to other coastal areas, particularly those with linear fringing reefs.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Wednesday 11 July, 1035, Hall B

Does dispersal connectivity matter for conservation?

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Connectivity among reefs is a keystone component for reef persistence and is often highlighted as a key factor to inform conservation decisions. This talk quantifies and discusses the benefits of incorporating dispersal connectivity for multiple different life histories into conservation prioritisation. Based on a case study encompassing the wider coral triangle, this project explores how conservation priorities change for contrasting life histories that represent species types. At the large scale of available data (including global ocean current products that underlie individual-based larval dispersal modelling), short and long distance dispersers influence regional conservation priorities minimally In contrast, we identify the types of species (by life history trait such as pelagic larval duration, spawning time, behaviour) that are most informative for conservation decisions at given spatial and temporal scales. Across all species, we show multi-species dispersal barriers that consistently drive conservation priorities where 'risk spreading' and 'representation' in reserves are desired. Building on broad conservation priorities based on current modelled connectivity estimates, we discuss how future altered connectivity patterns and disturbance regimes resulting from climate change may affect conservation decisions. We discuss these ideas in general, and illustrate their impact on pole-ward range shifts of tropical species We show how models of multi-species connectivity may influence regional conservation decisions on the Australian East Coast, ranging from the Coral Sea to subtropical regions.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1215, Hall B

Assessing connectivity of fish functional groups in a social-ecological seascape using a landscape ecology approach

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Shallow-water habitats within a tropical seascape are intimately connected through ontogenetic and/or feeding migrations of fish. The implications of these connections for food-web dynamics across boundaries are however not fully understood. Furthermore, the use of resources (e.g. fishing) needs to be considered as most coastal areas are heavily populated by humans extracting resources from the sea. In this study we examine the connectivity of important functional groups of coral reef fish between habitats within a social-ecological seascape in Zanzibar, Tanzania using a landscape ecology approach. We tested the relationships between landscape variables (distance, percent habitat cover, and configuration) and fish density and diversity within functional groups and life stages. Habitat data was collected at various scales ranging from 1m to >1km, using satellite imagery, aerial photography and ground truthing. Fish data was collected using a point census method. Furthermore, an interview-based study with fishers in the bay was conducted to account for different fishing pressure in the analysis. Our results show that percent seagrass cover within a 500m radius of coral reefs had strong influences on fish diversity within different functional groups. Coral reefs with large amounts of seagrass nearby harboured the greatest numerical abundance of mobile macro-carnivores (invertebrate feeders and invertebrate feeders/piscivores). Connectivity between patches of habitat is affected by habitat configuration and seems to be important in structuring coral reef fish assemblages. The use of landscape metrics may therefore be an appropriate method to consider in marine planning and the design of marine protected areas (MPAs).

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1200, Hall B

Quantifying coral substratum detectability from earth observation sensors

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Earth observation offers effective spatial and temporal coverage to monitor coral reefs in addition to *in situ* monitoring. Effective monitoring requires significant substratum features to be detectable by a sensor. This is affected by the sensor spectral resolution and the depth and composition of the water column. Most historical multispectral satellite sensors are incapable of effectively resolving reef substrata at depth. We quantified the level to which substrata can be classified by sensors with variable spectral resolution over a range of water depths and water qualities. Three sensors were selected, representing hyperspectral data (CASI with 30 spectral bands) and multispectral data (WorldView-2 with 8 bands, and QuickBird with 4 bands). Spectral separability of substratum reflectance spectra (convolved to the spectral resolution of the three sensors) were compared for oceanic and coastal water over incremental water depths. Metrics for substratum detectability and substratum separability were determined. The increased spectral resolution of the WV2 and CASI sensors, permits lighter substratum-types, such as abiotic reef material, bleached coral and light corals to be distinguished from the water column at greater depths, compared to QB. In a coastal water column, most substratum-types were indistinguishable at shallower depths than in the oceanic waters. Increased spectral resolution leads to more substratum types being separable from each other (substratum separability) at greater depth. This simulation study shows that higher spectral resolution (i.e. WV2 and CASI) earth observation data significantly enhances coral reef classification to increased depths thereby increasing the management relevance of this method.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
P196

Multi-disciplinary approach for coral reef management in Eparses Islands (SWIO)

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Knowledge on coral reefs of the Eparses Islands, SW Indian Ocean (Europa, Bassas da India, Glorieuses, Juan de Nova in the Mozambique Channel and Tromelin, East of Madagascar) is weak because of their limited accessibility. These islands should be classified as MPAs, which will require a management plan that must be based on fundamental knowledge of the coral reef communities. Faced with gaps in knowledge, and to meet the needs of managers, the BioReCIE program (Biodiversité, ressources et conservation des récifs coralliens des Iles Eparses) aims to 1) complete the data on the biodiversity of coral reef ecosystems through inventories (Algae, Cnidarians, Crustaceans, Echinoderms, Fish), set up an habitat classification (EUNIS), together associated with a database and a base geographic information system, 2) establish a baseline study of fish communities for estimating the state of resources on each island; 3) research potential indicators of disturbance to optimise environmental monitoring over the long term. A standardised methodology consistent with GCRMN methods was used to assess benthic and fish communities at the highest taxonomic level. Our results showed differences from north to south of the Mozambique Channel, likely due to their different geomorphology and degree of isolation, particularly for Europa and Glorieuse. Tromelin was characterized by specific low diversity of coral communities. The fish diversity and biomass were high on all islands, as was the presence of large herbivores and predators. These islands can serve as reference sites for the region, and gazetting them as MPAs will enhance this.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1630, Hall B

Modelling coral reef fish larvae dispersal for management

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The larval pelagic stage is probably the least known characteristic of reef fish and nevertheless the most important for population persistence. A better knowledge of this stage is fundamental for understanding connectivity between distant populations and adapting ecosystem management. Numerical dispersion models are increasingly used to guide spatial marine conservation planning and management. Assessing the validity of those models using empirical data is crucial to improve marine conservation worldwide. Here, we test a two-dimensional dispersal simulation model against otolith data collected on fish larvae. Data were collected during an episodic mass settlement of honeycomb grouper (*Epinephelus merra*) that occurred in 2002 in La Réunion (Indian Ocean). The dispersal model, implemented in the MGET toolbox, is based on pelagic larvae duration (PLD) and geostrophic current velocities derived from satellite altimetry (AVISO). The modeled connectivity patterns and the conclusions drawn from the otolith analysis (same age, same pool) are compatible. Connectivity for honeycomb grouper population between La Réunion and Mauritius islands is possible across the open ocean over a distance of 200 km. The mass fish settlement comes from Mauritius and is not locally recruited. Nevertheless, we insist that future dispersion models need to integrate improved biophysical parameters: vertical ocean stratification, larvae motion capacities and larvae environment related behavioral patterns. Then we discuss the implication of integrating connectivity within conservation and fishery management at local and regional scale. Finally, this study should be regarded as a contribution to the empirical validation of numerical dispersal model toward their application in data-poor regions.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1145, Hall B

The role of scale in understanding cold-water corals habitats

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The last decade of research has significantly improved our knowledge of cold-water corals in Eastern Canada, especially in the very extensive Newfoundland and Labrador waters. Indirect observations from fisheries bycatch in commercial fisheries and annual government fisheries surveys, have helped describing the species present, their abundance and geographic distribution. Such knowledge is critical to design appropriate management strategies that can protect coral biodiversity in cold-water environments. However, while bycatch data allow for some understanding of coral biogeography at a regional scale, it presents challenges when trying to understand the characteristics of coral habitats, and biological relationships between corals and other fauna, in more detail. Such knowledge is important to predict coral assemblages in unsampled locations. This paper presents recent and on-going research aimed at improving our understanding of cold-water coral habitats in Eastern Canada. Spatial statistical analyses of bycatch data in relation to oceanographic and geologic data found weak statistical relationships between corals and environmental variables. *In-situ* observations of corals, combined with high-resolution multibeam sonar measurements of bottom rugosity, were made in 2010 between 1000-3000m depth using a Remote Operated Vehicle (ROV). Ongoing analysis of this dataset suggests the importance of substrate type and topography on fine-scale coral distributions. While management decisions are frequently made at a regional scale using broad-scale data and analyses, detailed studies collecting finer scale data are required to understand the local variability and processes in place and should help implementing more effective protection mechanisms for corals at a local scale.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1645, Hall B

Savu Sea Marine National Park community mapping

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Savu Sea Marine National Park (MNP) is located in East Nusa Tenggara Province-Indonesia and is the largest marine protected area in the Coral Triangle (3.5 million hectares). Savu Sea has highly diverse coral reefs with a large number of endemic species as well as deep sea habitats which support a diverse cetacean fauna. In total, 18 species of whales, including Blue Whale and Sperm Whale have been recorded in this region. Fishing poses a threat to both the coral reefs through destructive and overfishing and cetaceans due to entanglement in gear and ship strikes. The development of Savu Sea MNP has reached the stage of establishment of Management Plan and Zoning Plan. One of the approaches that has been used to collect data information is community mapping. This involves community and stakeholders identifying special features such as sites of cetacean aggregation, SPAGs, tourism, fishing grounds and other threats to conservation targets and drawing them on the base map for each village. Survey location covered 110 villages in Savu Sea MNP area. The community mapping survey results were processed in an excel database and GIS-based geodatabase with detailed data set, and presented in 7 thematic maps that consist of: traditional fishing, commercial fishing, aquaculture, marine mammals, key habitats (mangroves, seagrass, coral, SPAGs, turtle nesting beach), tourism, and threats for conservation targets. Community mapping is a great tools to use in large MPA area like Savu Sea MNP. It will be an excellent resource when talking to communities and doing the zoning process.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
P198

Cost-effectiveness of habitat-based conservation planning for Solomon Islands coral reefs

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In marine environments, conservation planners face the challenges of implementing cost-effective approaches: conservation actions must maximize environmental benefits while minimizing costs to stakeholders. However, the availability and adequacy of required data on biodiversity, environmental services and socio-economic costs are often limited by severe constraints on logistics, time, and money. To overcome the difficulty of acquiring comprehensive data on biodiversity as quickly as possible and for a reasonable amount of money, marine habitats are widely used as surrogates of biodiversity in conservation planning. Many conservation projects and

academic studies use this approach assuming it is appropriate and valid. However, most underlying hypotheses are untested or poorly tested. In this context, the main goal of this three-year project is to understand the use of coral reef habitat maps as surrogates of biodiversity data for marine conservation planning in the Solomon Islands. Four factors are taken into account: 1) the challenges in mapping and classifying coral reef habitats; 2) the level of information on biodiversity provided by different types of habitat maps; 3) the ecological processes driving the potential of coral reef habitats as surrogates of biodiversity; and 4) the costs and benefits of using habitat-based conservation planning for coral reef biodiversity. We will enlarge on these four considerations, describe our methods and report findings to date.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1730, Hall B

A new dimension to 'ridge to reef' mapping in Melanesia

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The indigenous communities of Choiseul province, Solomon Islands, have embraced locally-managed conservation areas for their land, marine and coastal resources under a plan for a 'ridge to reef' network. In Manus province, Papua New Guinea, concern over climate change impacts has led to requests for support in establishing a similar island-wide network of protected areas to help manage ecosystem services, especially coral reefs. In both Manus and Choiseul, there is a different level of participation by individuals within their communities in understanding and contributing to decision-making over marine and terrestrial protected areas. An innovative tool to aid participation in planning and decision-making, called participatory 3D modeling (P3DM), was implemented with the Mboeboe community in Choiseul in February 2011, and with the Manus Provincial Government in Lorengau, September 2011. P3DM combines community mapping with open discussions on land-use planning scenarios. It integrates geographic precision with local spatial knowledge of participants and 'mind-maps' of locality and familiar settings. In both cases, 'roundtable' access to the model by up to 50 people at the same time, all with a better cognitive understanding of their landscape and relation between features on the 3D map, allowed a much deeper level of participation by community members in local planning discussions. Participants were able to 'talk to the model' to explain issues and concerns, rather than confront authority and protocol. In both Choiseul and Manus the use of P3DM has added a new dimension to participatory 'ridge to reef' conservation planning and protected area design and designation.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Wednesday 11 July, 0930, Hall B

Management implications of intra-habitat spatial variability in coral reefs

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Understanding how corals respond to spatial seascape heterogeneity is essential for effective conservation and management. Repeatedly, reef heterogeneity within the seascape (variation in reef size, spatial configuration, and structure at meso-scales of 100's m - km's) has been overlooked in coral diversity research frequently conducted at local scales. Here, we used high-resolution satellite imagery and image analysis techniques to quantify reef heterogeneity beyond the local scale for Caribbean patch reefs. We then evaluated spatial patterns in coral community composition among patch reefs to show that coral species are neither randomly distributed, nor spatially autocorrelated. Rather, coral distributions correlated significantly with metrics of reef heterogeneity. We show that this relationship between reef heterogeneity and coral composition can introduce bias into methods for (1) monitoring coral richness and (2) assessing marine performance. We first demonstrate that common methods for monitoring coral richness (using equal numbers of transect sub-samples among reefs of varying size) can underestimate the true species richness of larger reefs by 15%, solely due to sampling effects. Second, we show that reef heterogeneity can significantly confound assessments of marine reserve performance. We conclude by presenting an innovative method, using advances in remote sensing and image analysis, to control for reef heterogeneity during reserve assessments. In summary, this research advances our understanding of how meso-scale spatial heterogeneity, within a single geomorphic type of coral reef, influences coral community composition at the local scale and demonstrates how we can apply this knowledge to improve coral management.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1230, Hall B

Reconciling conservation with socio-economics – Philippine cases review

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Overexploitation, habitat degradation and poor or non-existent management mean that many small-scale, artisanal fisheries are in decline. Management of these fisheries is often inadequate or absent, partly because they are data-poor. Baseline data and new management approaches, particularly those relevant to developing countries, are urgently needed. No-take Marine Reserves (MPAs) are advocated widely as a management option for multi-species tropical fisheries and as a potential solution to the loss of marine biodiversity, ecosystem structure and overfishing, and thus for sustainability. Tremendous work has been done on the qualitative merits of MPAs. In fact, however, the quantitative evidence to support MPA-efficacy in protecting biodiversity and enhancing fisheries is highly limited, creating scepticism about MPA-benefits among local communities: Do fishery yields improve enough to compensate for the lost fisheries areas? How to bridge the gap between conservation and livelihood needs? To meet these questions, underwater visual censuses in and outside MPAs, fishery and socio-economic surveys were conducted in twelve districts, comparing MPA and non-MPA sites within two municipalities in South-Cebu (Philippines). Preliminary results show: when people are hungry, their need for food necessarily comes before their willingness to protect the environment, even if ' in the long run' conservation would provide them with more food. So any attempts to protect marine life must also simultaneously provide clear and clearly understood benefits to all stakeholder groups, especially to fishers, who temporarily endure catch losses due to the lost fishing areas.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
P199

Comparing Kompsat-2 with *in situ* approaches for habitat monitoring in Weno Island

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The Korea South Pacific Ocean Research Center (KSORC) is located in the tropical South Pacific at Weno Island, Chuuk state of Federated States of Micronesia (FSM). Weno Island coastal is surrounded by a typical fringing reef and the reef is composed of mangrove forests, seagrass bed and coral reefs. We have been monitoring the reef in early 2011 to evaluate current conditions of those habitat. In September 2010, the reef around KSORC have been mapped using the Korean Multi-purpose Satellite-2 (Kompsat-2) image data. In this study, we classified habitat distribution using *in situ* survey on the northeastern coast of Weno Island and compared the survey data to the Kompsat-2 habitat classification. The objective of this study was to utilize photo-quadrat method (PHOTS) data to enhance the accuracy of remote sensing image classifications. The three transect lines were designed to traverse the reef from coast to slope area; the length is around 240m (TL1), 780m (TL2), 490m (TL3). Each line was sampled every 10m with a 1m X 1m quadrat and pictures were taken with a Cannon G10 digital camera. We simplified the Australia Institute of Marine Science (AIMS) substrate classification scheme to match the resolution of the remote sensing image classification. The image processing procedure showed five dominant substrate types: sand (46%), seagrass (27%), coral (5%), rubble (7%), fleshy algae (12%). The Kompsat-2 classification displayed a similar substrate types in its remote sensing image classification.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
P200

Forest conservation delivers highly variable coral reef conservation outcomes

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Coral reefs are threatened by human activities on both the land and the sea. Most conservation planning for coral reefs focuses on removing threats in the sea, neglecting management actions on the land. A more integrated approach to coral reef conservation, inclusive of land-sea connections, requires an understanding of how and where terrestrial conservation actions influence reefs. We address this by developing a land-sea planning approach to inform fine-scale spatial management decisions and test it in Fiji. Our aim is to determine where the protection of

forest can deliver the greatest return on investment for coral reef ecosystems. To assess the benefits of conservation to coral reefs, we estimate their relative condition as influenced by watershed-based pollution and fishing. We calculate the cost-effectiveness of protecting forest and find that investments deliver rapidly diminishing returns for improvements to relative reef condition. For example, protecting 2% of forest in one area is almost 500 times more beneficial than protecting 2% in another area, making prioritization essential. For the scenarios evaluated, relative coral reef condition could be improved by 8-58% if all remnant forest in Fiji were protected rather than deforested. The general results will support decisions made by the Fiji Protected Area Committee as they establish a national protected area network that aims to protect 20% of the land and 30% of the inshore waters by 2020. Although challenges remain, we can inform conservation decisions around the globe by tackling the complex issues relevant to integrated land-sea planning.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1515, Hall B

Coral reef connectivity in the Indian Ocean

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Although the Indian Ocean is an area of great interest for coral reef conservation (e.g. Chagos, Andaman Islands, Madagascar, Arabian Peninsula), relatively little is known regarding connectivity patterns among reefs within this region. To address this, large-scale simulations of connectivity patterns were carried out for both coral and fish species of the Indian Ocean. The results provide a first look at the spatial and temporal relationships between Indian Ocean coral reef ecosystems. The data can be also used in conjunction with planning algorithms for designing large-scale marine reserve networks.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1130, Hall B

Incorporating connectivity and climate change into marine conservation planning

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Systematic conservation planning has been recognized as the most coherent framework to address marine reserve design and to promote the effective management of marine protected areas. Despite the efficiency of these methods, it is acknowledged that most of its applications do not comprehensively incorporate biological processes or dynamic threats. We investigated how well conservation planning has addressed ecological connectivity and climate change effects, two important concerns to ensure the long-term viability of biological assemblages. A review of literature identified that 89 studies addressed connectivity and 40 addressed climate change effects, showing that conservation planning is faced with an extensive array of alternatives to deal with both issues. However, the practical application of management to deal with connectivity and climate change is limited. Although connectivity has been incorporated quantitatively (by almost 45% of the approaches) - a desirable manner to set conservation objectives - few approaches had any ecological significance when applied. The results are even worse for climate change, illustrating that more effort should be made to facilitate its explicit application into conservation planning (more than 85% of approaches are merely qualitative). Since shortcomings in applying these approaches are still widely evident in the literature, recent advances in the understanding of the dynamic nature of these processes needed to be made operational in planning. This will allow managers and conservationists to develop a portfolio of options to enhance the long-term effectiveness of conservation planning.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1500, Hall B

Integrating land-sea connectivity into systematic conservation planning

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Systematic conservation planning identifies priority areas for action. For marine conservation, considering only actions in the sea is not always effective, as land-based activities can affect reef conditions. Here we present a case study integrating connections between the land and the sea into systematic conservation planning in Fiji. We represent land-sea connectivity by the distance from river mouth to each reef and forest area of terrestrial catchment. Assuming that forest cover reduces run-off, we prioritise terrestrial catchments with more than 50% forest cover and their recipient reefs to focus on preserving reefs less threatened from land. We achieved the conservation outcomes while minimising opportunity costs from logging and fishing. We explore how priority areas change when

connections between the land and the sea are included, and also how focus on the directionality of the connections (direction from land to sea) alters selection. Our results show that when we account for connections between the land and the sea, high priority marine areas are linked to high priority terrestrial areas. Further, if the directionality is not considered, there are clusters of marine priority areas that are connected to a single high priority terrestrial area. By accounting for directionality, selected marine priority areas are connected to the overall high priority terrestrial areas in our planning region. Integrated planning increases the percentage of protected reefs that are linked to high priority terrestrial area by about 20% with only a marginal increase in cost.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1530, Hall B

Human coastal use mapping for coral reef priority management sites

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Understanding human interaction with coral reef resources is key to improving coral reef management. However, limited information is currently available regarding the specific locations or intensity of the wide variety of human activities that take place in coral reef areas. The Coastal Use Mapping Project is a means of gathering detailed spatial information on human uses and activities in coastal areas to improve management planning and assist in monitoring the effectiveness of management actions for coral reef conservation. Information is gathered through facilitated participatory mapping workshops, where local stakeholders are engaged to provide spatial data on the locations, intensity, and other important aspects of multiple human uses and activities. This information is combined with pre-existing data sources to create geospatial products for coastal managers and local community groups. Products include GIS data, map booklets of human uses, and an interactive tool that allows users to examine the relationships between multiple human uses of coral reef areas, as well as the associated watershed. To obtain accurate information through participatory mapping, it is important to engage appropriate local resource users, managers, and residents from a variety of backgrounds. While challenging, the involvement of local residents improves the accuracy of end results and helps to gain local buy-in for both the process and project outcomes. This project was piloted at two priority sites for the state of Hawaii Coral Program, and is being adapted and expanded over the next three years to include additional coral reef priority sites in US states and territories.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Wednesday 11 July, 1040, Hall B

Filling the gaps: spatially representing social and economic indicators

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The Great Barrier Reef Marine Park was the world's first declared large-scale marine protected area. The park is a multiple-use resource and supports key activities such as commercial fishing, tourism, recreational fishing, shipping and traditional use. It is estimated that the Great Barrier Reef contributes $5.8 billion annually to the Australian economy. Since the establishment of the Great Barrier Reef Marine Park in 1975, a variety of social and economic research has been conducted to support planning and management. Nevertheless, much of this research is yet to be linked to broader frameworks for understanding human dimensions of resource-use and marine park management problems and decision making. The multi-year National Environmental Research Program (NERP), CSIRO and James Cook University are addressing this gap by examining a number of indicators and developing a long term social and economic monitoring programme for coastal communities, catchment industries, marine tourism, commercial fishing, aquaculture, recreation, traditional owners and shipping sectors in the Great Barrier Reef. Using a spatial approach we are able to characterise the spatial and temporal heterogeneity of human uses and analyse how these uses relate to the complex human and natural systems in which they are embedded. This study can positively contribute to marine spatial planning, management and long term monitoring designed to achieve ecological, economic, and social objectives.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1700, Hall B

Reef conservation promoted by public aquaria and scientists: SECORE

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SECORE (SExual COral REproduction) is an international initiative of public aquaria and research institutions to promote coral reef conservation (www.secore.org) through public outreach, annual training workshops and collaborative research projects between public aquarium professionals and scientists. In the past seven years, SECORE has organized annual field workshops during coral mass spawning events in the Caribbean and the Pacific. During these workshops, public aquarium professionals are trained in aquaculture and breeding techniques using sexually produced coral larvae and scientists are introduced to the type of conservation science carried out by public aquaria. The practical knowlegde of aquarium staff and the theoretical background of scientists have created an effective synergy which has led to promising results in conserving endangered coral species such as *Acropora palmata*. These include establishment of settlers in public aquaria, novel cryopreservation and genome banking techniques and quanitifcation of thermal tolerance in coral larvae. SECORE has set up the first permanent coral nursery on Curacao (Netherlands Antilles) for a restoration project addressing endangered corals and to raise awareness in the local community. Due to the training and collaborative efforts of past years, SECORE teams worked in parallel at three field locations during the 2011 spawning of *A. palmata*. The activities could be followed by people all over the world through social media and educational programms of the participating public aquaria and SECORE's more than 60 member institutions. These tools have expanded our network to help interface with a wide range of people of varying social background.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
P201

Marine sensitivity mapping of the southern coast of Yemen: from Balhaf to Mukalla

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In Yemen, the fisheries and coastal resources account for the most important source of non oil and gas export revenues for the country. Although the knowledge of biological diversity and coastal ecosystems structure and functioning in this area has increased in the last two decades, most of the information has remained in the grey literature and never compiled for an efficient coastal management. The objectives of the project were to provide the local decision makers with a comprehensive document including detailed maps and descriptions of the coastal ecosystems as well as a detailed account of the composition, structure and distribution of high and low cover coral dominated assemblages. A sensitivity mapping of the marine habitats was produced in order to allow the identification of areas to protect in priority. The approach consisted of a multi step and multi-disciplinary process including: i) remote sensing of the area using High Resolution Satellite Images (WorldView2), ii) field surveys to validate and complete the photo-interpretation and conduct coral communities assessments, iii) an adapted sensitivity scale, iv) a GIS project and edition of detailed maps, v) an atlas with detailed description of the coastal environment of the area. This multi-disciplinary approach led to a detailed assessment of the coastal environment combined with broad scale cartography. The deliverable will be directly used to implement conservation measures of the sensitive ecosystems in the area. This work was financed by the YemenLNG Company as its commitment to support the implementation of protected areas near its operational site.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
P197

Satellite imaging coral reef resilience for regional scale management

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The spatial distribution of parameters underpinning coral reef resilience is poorly characterized. This hinders direct integration of the resilience concept into management. Through satellite and acoustic remote sensing, our goal is to quantify and map relevant biological, physical and anthropogenic measures. Focusing on the Saudi Arabian Red Sea we present a rare synergy in data collection; exhaustive reef-scale survey of resilience parameters coupled to coarser but spatially continuous remotely-sensed assessment. Data from publically available satellites (MODIS, Google Earth) were assembled at no cost, and combined with commercial satellite imagery (QuickBird, DigitalGlobe Inc.). Benthic habitat maps are derived across a vast geographic span (>20,000 km^2) with high spatial acuity (7.5m^2 minimum mapping unit). Satellite imagery also underpins map-based assessment of other regionally important parameters (e.g. water depth, thermal regime, fishing pressure, development etc). Principles of coral reef ecology and both field and remotely-sensed observations are all used to develop map-based indices to capture components of resilience. A method for assimilating these measures into a spatial proxy for reef resilience is described, and the first-basis for a remotely-sensed resilience index (RSRI) presented. The index provides a spatial foundation with which to better understand the geographic patterns and management implications of reef resilience.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1545, Hall B

Mapping impacts of small-scale fishing on coral reefs

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Destructive and illegal fishing in small-scale artisanal fisheries is a management problem of concern worldwide. However spatial heterogeneity in the severity of their impacts is largely undocumented. Using an innovative combination of social-ecological data and spatial tools, we considered how the spatial distribution of small-scale (and undocumented illegal) fishing has affected the Danajon Bank, a coral ecosystem in the Philippines, from 1941-2011. We developed detailed maps of spatial and temporal changes in fishing practices - specifically of gear distributions and frequency of use - by interviewing 357 fishers in 23 coastal communities. Our goals were to determine (1) what proportion of the ecosystem is targeted by different fishing gears and (2) how the frequency and severity of habitat-impacts vary spatially. We found that while fishing affects most of the Danajon Bank ecosystem, there is a complex distribution of fishing frequency and severity. Therefore the frequency that a fishing ground was targeted did not indicate the severity of fishing impacts to its habitat. Illegal gears are used widely, yet did not always have severe habitat impacts. Thus illegal fishing is not a good proxy for destructive fishing. Spatial patterns of fishing change over time and feedbacks between illegal fishing, regulations, and ecological conditions appear to influence the condition of the ecosystem and the choices made by fishers. Our research demonstrates that a spatial understanding of small-scale fishing practices can help management become more sustainable.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1715, Hall B

The importance of biological information in marine reserve design

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Marine reserves systems are often designed using environmental data, as the cost of obtaining comprehensive biological information is high. However we don't know the effectiveness of this approach for marine systems. We design marine reserves in four different ways and test how well those systems represent biological data collected from 1189 sites on the Great Barrier Reef (GBR), Australia. The designs included 30% of: a random selection of the GBR; the 35 bioregions defined in the government marine park zoning of the Great Barrier Reef; the 35 environmental domains created using x environmental equally weighted variables collated at a 0.01 degree resolution; and the 35 environmental domains where the environmental variables were weighted based on biological importance. We assumed that if 30% of the total biomass of a species was protected within the marine reserve system, it was adequately protected. The number of species with adequate protection was then compared between the four scenarios as a measure of success. We found that random reserve design protected the highest number of species (377 out of a total of 842 species). For the three non-random approaches, the number of adequately represented species ranged between 351 and 361, out of a total of 842 species. This low overall representation indicates that biological

data is explicitly needed to ensure reserves comprehensively protect biota. We have discovered that environmental surrogacy approaches to marine seabed conservation are likely to fail. This supports investment in biological data collection for effective conservation design.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Wednesday 11 July, 1030, Hall B

Designing marine protected areas using uncertain habitat information

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Informed conservation decision-making considers uncertainty associated with ecological data. One of the most pervasive forms of uncertainty in data used to make conservation decisions is caused by habitat mapping errors. Here, we developed a novel spatial conservation prioritisation approach that accounts for the uncertainty inherent in coral reef habitat maps derived from remote sensing data. We used multi-scale habitat maps created using object-based image analysis from satellite (Quickbird, Ikonos) data depicting geomorphic zones and benthic communities, where habitat misclassifications were estimated through validation with field data. Using the Kubulau fisheries management area in Fiji as a case study, we designed a marine reserve network with a high probability of protecting every habitat type based on habitat class accuracy. We compared the outcomes of our approach to those of standard reserve design approaches, where habitat mapping errors are unknown, to demonstrate how inclusion of accuracy data changes priority areas for reservation, and examine trade-offs between the costs of collecting such uncertainty data and representation of habitats in marine reserves. We found the inclusion of uncertainty into marine reserve design influenced the location of priority areas and conservation costs, with areas of high mapping certainty significantly favoured over areas of intermediate certainty. The importance of including accuracy data in spatial conservation prioritisation approaches was highlighted in this study. Results can be used to provide recommendations to local stakeholders to ensure better management of the existing conservation efforts and inform decisions about the location of revised reserve networks at various scales in Fiji.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Wednesday 11 July, 1000, Hall B

Defining regions by benthic habitat morphology along a latitudinal gradient

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Marine organism diversity typically attenuates latitudinally from tropical to colder climate regimes. Since the distribution of many marine species relates to certain habitats and depth regimes, mapping data provide valuable information in the absence of detailed ecological data that can be used to identify and spatially quantify smaller scale coral reef ecosystem regions and potential physical biogeographic barriers. This study focused on the southeast Florida coast due to a recognized, but understudied, tropical to subtropical biogeographic gradient. GIS spatial analyses were conducted on recent, accurate, shallow-water benthic habitat maps to identify and quantify specific regions along the coast that were statistically distinct in the number and amount of major benthic habitat types. Habitat type and amount were measured for 209 evenly-spaced cross-shelf transects. Evaluation of groupings from a cluster analysis at 75% similarity yielded five distinct regions that were supported by an analysis of similarity. The number of benthic habitats decreased with increasing latitude from 9 in the south to 4 in the north and many of the habitat metrics statistically differed between regions. Three potential biogeographic barriers were found at the Boca, Hillsboro, and Biscayne boundaries, where specific shallow-water habitats were absent further north. The Bahamas Fault Zone boundary was also noted where changes in coastal morphologies occurred that could relate to subtle ecological changes. The analyses defined regions at a scale appropriate to regional management decisions, hence strengthening marine conservation planning with an objective, scientific foundation for decision making. They provide a framework for similar regional analyses elsewhere.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Tuesday 10 July, 1245, Hall B

Towards marine spatial planning for Hervey Bay's coral reefs

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Values and connections of coral reefs within subtropical Hervey Bay, south of the Great Barrier Reef (GBR), were characterized with a view to their inclusion as inputs to local and regional planning. The approach included: (1) mapping of reefs; (2) assignment of biodiversity and geomorphic values; and (3) identification of specific policy implications. In-situ substrate and species datasets for both dominant communities (matching Quickbird satellite image resolution) and for low density species were used to define a reef typology for mapping and connectivity analyses. User's and producer's accuracies for identifying homogeneous (dominant) geomorphic substrates on images were generally high (coral 60-65%; sand 85%), but predicting taxonomic reef type from the images was intractable (Tau 46-49%). Field investigations at high taxonomic resolution revealed that a number of regionally rare and high latitude species are present in Hervey Bay. Its dominant communities resemble GBR nearshore reefs (i.e. reef-forming *Turbinaria*, *Goniopora* and *Acropora*) more closely than they do subtropical (faviid-dominated) coral communities, reflecting historical and/or present larval connectivity with the GBR. Hervey Bay's reefs are part of a reef-seagrass-mangrove complex that is one of three such complexes in the region. Flood plumes from the region's Mary and Burnett Rivers extend northward across the GBR lagoon to the Capricorn-Bunker reef group, episodically linking these reefs functionally to the GBR via biota and nutrient fluxes. Overall, our results provide the types of information needed to support marine spatial planning for coral reefs in the context of the catchments and oceanographic processes that influence them.

18C Spatially-explicit & multi-disciplinary approaches for coral reef conservation
Wednesday 11 July, 0945, Hall B

18D Strengthening science-management partnerships

Science and public input: Biscayne National Park's proposed Marine Reserve

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Biscayne National Park (Florida, USA), an overfished marine protected area, proposed a 10,522 acre no-take marine reserve in its draft General Management Plan in September 2011, in order to provide snorkelers and divers the opportunity to experience healthy, natural coral reefs. With no standard planning guides for the Department of the Interior regarding marine reserves, the park identified the factors that would lead to enhanced visitor experience (diversity, abundance, and large size of fishes; coral diversity and health; reefs with structure; and presence of shipwrecks), and ensure effective management and ease of enforcement (visual markers and single reserve instead of multiple reserves). In 2009, the planning team presented to the public a summary of data from universities, other federal agencies, and park scientists, and asked the public to propose the size, shape, and location of the reserve(s). The public-proposed designs were then presented to a panel of scientific reviewers for ranking on which designs were most likely to achieve the desired objective. The park planning team then created a final set of alternative designs to propose in the draft plan that was presented to the public in 2011. The three public meetings were well-attended and comments ranged from supporting a larger marine reserve to questioning the science and intent of the marine reserve.

18D Strengthening science-management partnerships
Friday 13 July, 1130, Hall C

MPA evaluation and habitat characterization for vulnerability assessment in Davao, Philippines

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Sta. Cruz in Davao del Sur was assessed to attain sound management interventions as well as climate change mitigating and adaptation measures in terms of its exposure to stressors, its sensitivity given the existing seagrass ecosystem in the area, and adaptive capacity with its locally-managed MPA. It is one of the sites of the national program on Resilient Seas under the project 'Invertebrate Fisheries Population as Response Indicators for Climate Change.' Based on the recent monitoring and evaluation conducted by ECOGOV , the marine protected area (MPA) in the study site is still on Level 1 which implies that the management strategy is just being established, with the preliminary requirements (e.g. municipal ordinance, management body IEC, budget allocation, etc) being complied. With the gross habitat characterization conducted, the study site was found out to be mostly occupied by seagrass with *Enhalus acoroides* as the dominant species. Mean percent cover did not vary much from among the inside of the marine sanctuary (34 to 52%), within the buffer zone (25-51%), and in the open access (38-48%). Likewise, values for the mean density show slight variation which range between 71 to 152 shoots/m^2 for the three zones surveyed. The

substrate type in the study station is sandy with presence of coral rubbles in some transects. Some invertebrates, such as sea cucumber and sea star, were also observed.

18D Strengthening science-management partnerships
Friday 13 July, 1430, Hall C

Coral reef monitoring and management capacity building in the Bahamas

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The Kerzner Marine Foundation has funded The Blue Project since 2007, to increase capacity for coral reef conservation in the Bahamas. Local partner organizations include: The Bahamas National Trust a quasi-governmental organization mandated to protect all national parks in the Bahamas; The Bahamas Reef Environment Educational Foundation, which focuses on grassroots marine science education and advocacy for marine resource conservation; The Bahamas Government- Department of Marine Resources, mandated to protect economically important marine fisheries and The Nature Conservancy's- Northern Caribbean Program, an international non-profit conservation organization. Through the project, the partners have distributed coral reef educational materials to more the 90 schools on more than 7 islands reaching more than 9,000 students and developed new materials to support marine science teacher training. The group has supported training for scientists in coral reef and fish population monitoring and management to support science based protection of coral reef habitat and fisheries resources. The project has contributed to high resolution data for local coral reefs and updating area maps to support conservation activities that will protect representative coral habitat and fish populations. By using the best possible techniques and training local scientists to engage in monitoring at a higher standard, the project seeks to improve the quality of habitat protected throughout the Bahamas.

18D Strengthening science-management partnerships
P202

Managing for recovery: translating monitoring into management decisions in Indonesia

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In 2005, 1.2 million hectares of the waters and reefs in Berau, Kalimantan, Indonesia were declared as a marine protected area (MPA) by the local government. However destructive fishing and other threats continued because a system of management was not implemented following declaration of the MPA boundary. Reef surveys were conducted in 2011 to assess the status of the reefs in Berau and to provide information for renewed management planning. Information was collected on benthic and coral community composition, coral size class, coral disease and fish biomass at 20 sites throughout the MPA. The results showed that compared to previous studies of coral communities in 2003 and 2009, there has been a significant decrease in coral cover. There has been a loss of almost all coral cover over the past two years at some sites and coral communities are dominated by small size classes (<40 cm diameter). We used these data to identify sites which have high potential for recovery, based on characteristics including available substrate for coral settlement, high biomass of herbivores and low prevalence of coral disease. We recommend these sites are prioritised for management using a community-based management approach. Given it is likely that effective management of threats to Berau reefs will take some time to achieve, it is important to manage these reefs to maximise the recovery process and restore reef function rather than prioritising protection of high biodiversity sites.

18D Strengthening science-management partnerships
Friday 13 July, 1200, Hall C

The role of knowledge in local government planning for climate change

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To ensure communities are resilient to climate change requires planning for adaptation to changing climate in the short and longer term. A key feature of resilient communities is their ability to build a range of knowledge for learning and problem solving. Decisions about climate change need to be made, yet how to acquire, synthesise and use knowledge to inform planning policy and decisions for climate change are critical challenges. Climate change is framed as the province of both experts and international agreements around mitigation of greenhouse gases. Scientific knowledge has occupied centre stage as the IPCC presented the 'consensus view of the leading climate change experts in the world'. Useful at national scales, these high level assessments privilege certain types of knowledge and mask some of the societal choices required concerning climate impacts. Adaptation by communities

needs to be locally organised and so the application and interpretation of knowledge relevant to climate change information is required at the local level. Local governments are a key agency to manage adaptation at a community level. Yet local government decision making is largely determined by decisions at other scales. Additionally the knowledge that local government decision makers bring to the process determines their willingness to embed climate change in council planning. This paper focuses on the important elements of knowledge of climate change at the local level and how that knowledge is framed within local government contexts using case studies of two local governments in the Great Barrier Reef region.

18D Strengthening science-management partnerships
Friday 13 July, 1230, Hall C

Engaging with and coordinating across research programs to optimise investment

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Investment in Great Barrier Reef science is delivered through a range of programs and government initiatives, as well as through co-investment from the private sector. Similarly, Great Barrier Reef science is conducted by a range of entities, primarily universities and government scientific organisations. A large proportion, but not all, of the science conducted on the Great Barrier Reef is intended to inform and support management and protection of the ecosystem and the goods and services that it provides. A variety of Australian and Queensland Government agencies and other stakeholder organisations contribute to the protection and management of the Great Barrier Reef Marine Park. These agencies and organisations have specific management objectives and priorities and therefore different science information requirements. Despite these differing objectives, there is a spirit of cooperation and collaboration between agencies, as well as between research providers. The Great Barrier Reef Outlook Report provides the basis for identifying information gaps and scientific needs for management of the Great Barrier Reef, which are then compiled and published to guide future research investment. The major research programs are multi-institutional and multi-disciplinary and are governed through advisory and steering committees. Management agencies and research institutions as well as a range of stakeholders are represented on these committees and there is significant overlap in membership between programs. These approaches coupled with project-level engagement of management agencies and research providers have facilitated dramatically improved research coordination and optimisation of investment.

18D Strengthening science-management partnerships
Friday 13 July, 1215, Hall C

How science drives management changes in Florida Keys National Marine Sanctuary

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Since its designation by the U.S. Congress in 1990, Florida Keys National Marine Sanctuary has worked to address human influences to the coral reef ecosystem of the Florida Keys. Sanctuary management actions, including the prohibition of pollution discharges and the designation of highly protected zones, have helped to improve water quality, increase the size and abundance of some fish species and spiny lobster in sanctuary reserves, and document the return of some historic fish spawning aggregations. However, human actions such as poaching, development, vessel groundings, and marine debris continue to negatively affect the coral and seagrass habitat and living resources, but they may be improved with long term management efforts, regulatory compliance and community involvement. The sanctuary's Condition Report, released in October 2011, provides an important baseline on the status of sanctuary resources and now guides the first comprehensive review of sanctuary regulations, its marine zoning scheme, and its management plan. With increased knowledge of how management actions are improving certain conditions as well as a better understanding of emerging threats such as climate change, ocean acidification and invasion of Indo-Pacific lionfish, Florida Keys National Marine Sanctuary is adapting its management, regulation, and zoning scheme to further protect and restore the area's natural resource and ecological qualities. While this public process is only beginning the sanctuary's advisory council is exploring further protections of coral restoration areas, heavily fished spawning aggregations, seagrass beds impacted from errant boaters, and expanding large marine reserves for maintenance of important biological communities.

18D Strengthening science-management partnerships
Friday 13 July, 1115, Hall C

Sustainable Research Vessel

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We project to design and build a Sustainable Research Vessel (SRV) for studying and exploring fragile marine ecosystems without disturbing them. The SRV aims to be an efficient research vessel, enabling researchers to explore and study, pristine and diverse ecosystems (e.g. coral reefs) with a minimized carbon footprint and little impacts on explored areas. After discussion with scientists and boat builders, the SRV project will focus on the production of a sailing catamaran. The Research Vessel will carry on-board the latest technology available in renewable energy (wind, solar, hydrodynamic) and waste management (water recycling, waste minimizing), and be built with sustainable materials (bio-composites). Therefore, this will be the first Research Vessel ever designed and built specifically to study and respect the environment. Classical Research Vessels, whose missions are to study the fragile biodiversity of marine ecosystems, unfortunately have significant impacts on their direct environment, such as greenhouse gas emissions, sound and vibration disturbances, disposal of grey water, dumping of engine cooling water, and residual oils. On the other hand, the SRV will use sails (or electric engines when no wind) and will eliminate such direct impacts (gas emissions, dumping of cooling water & residual oils & fuel) and ultimately enhance the protection and viability of the environment. Therefore, SRV is a unique project that is needed for the future of marine exploration and research, because climate change will soon oblige us to change our ways of life and our ways of studying and exploring the planet.

18D Strengthening science-management partnerships
Friday 13 July, 1445, Hall C

Improving management effectiveness of the Marine Reserves of Rodrigues, Western Indian Ocean

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Intensive fishing pressure in the Rodrigues lagoon has resulted in drastic declines of both fin-fish and invertebrate landings and the degradation of lagoon habitats. In recognition of the status of the marine resources, four marine reserves were identified by the local fishing community and proclaimed by the local government in 2007, but implementation had stalled, partly due to the lack of a management plan for the reserves. It is now well documented that management effectiveness can be improved when local marine resource users are more involved in management processes. While this is usually achieved through consultation, this project aimed to progress the implementation of the reserves by empowering local stakeholders to actually plan the management of the four reserves. A series of training workshops were held to build local capacity in management planning and to capture local knowledge using participatory mapping techniques. Through the workshops, participants devised and agreed the management vision, goals, objectives, strategies and actions. A core group of stakeholders (fishers, representatives of the local marine conservation NGO, tourism representatives and fisheries enforcement officers) used the workshop outputs, results of previous scientific studies and their local knowledge to draft the plan. Extensive consultations were held with the local communities and tour operators to ensure their interests were taken into consideration. The process used to complete the draft management plan developed a strong sense of ownership amongst the local community and it is expected that this participatory approach will improve compliance and management effectiveness of the marine reserves.

18D Strengthening science-management partnerships
Friday 13 July, 1400, Hall C

Potential cumulative impacts of swim-with activities on dwarf minke whales

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Worldwide, concerns about potential negative impacts of whale-watching tourism are growing and numerous studies have shown short- and long-term consequences of human activities. Swim-with whales programs in particular present special management challenges and such activities were considered by the International Whaling Commission as potentially 'being highly invasive'. This study uses photo-identification data collected onboard nine vessels involved in swim-with programs in the northern Great Barrier Reef to investigate the potential for cumulative impacts of the activities on dwarf minke whales. Of the

whales identified in 2006 (195 whales) and 2007 (171 whales), around one third interacted at least twice with vessels and swimmers over the course of a single season (29% and 33% in 2006 and 2007, respectively). Individual whales stayed in the interacting population for a relatively short time, with the mean time interval between first and last sighting being eight or ten days in 2006 and 2007, respectively. This finding indicates regular immigration and emigration from the interacting population, which are characteristics of an open population. The recorded cumulative interaction durations for individual whales varied greatly between different animals, varying from just over an hour to nearly 42 hours for the duration the individual remained in the area. The findings of this study raise concerns about potential cumulative impacts of the swim-with whales activity on individual dwarf minke whales and helps to inform the sustainable management of the industry.

18D Strengthening science-management partnerships
Friday 13 July, 1145, Hall C

Teardrop: a rapid reef mosaicing tool for coastal communities

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We demonstrate that Teardrop's a rapid reef mosaicing tool that can make fast and frequent surveys of shallow reefs at low cost. The hardware component is a hollow, teardrop-shaped wing that holds a waterproof digital camera in video mode while being towed by a boat or a swimmer over reefs. Captured video are parsed into images and stitched using Microsoft Image Composite Editor (ICE), a free panorama stitching software. Using this tool, we have shortened the time to make a composite image of the reef floor from one week to one day. Our aim is to make Teardrop easy to use and to deploy to coastal resource managers, local government units or marine scientists such that they can do the reef surveys themselves. Traditional reef video surveys are costly because of the logistics involved in bringing experts, divers, and their equipment to a site. Using Teardrop mounted with a commercial underwater camera is cheaper to maintain and less difficult to manipulate than using a remotely operated vehicle (ROV). In addition, it can cover a larger area if towed by a banca. Bancas are slender, outriggered boats used by most fishermen in the Philippines. We report Teardrop's performance and our experience in deploying Teardrop to different coastal communities around the Philippines.

18D Strengthening science-management partnerships
Friday 13 July, 1415, Hall C

18E The future of the Coral Sea reefs & sea mounts

New light on dark depths: Australia's Coral Sea landscape

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The undersea landscape of Australia's Coral Sea comprise vast abyssal plains, bordered by submerged plateaus and separated by broad troughs and valleys. Superimposed over these major features are emergent coral atolls, some of the largest in the world, and an extensive seamount chain of drowned guyots, or in places capped with coral reefs. Mapping this undersea landscape is a challenge but through a series of bathymetric surveys using the RV Southern Surveyor and other vessels of opportunity, advanced mapping techniques now reveal the finer-scale detail of the seabed. This talk will discuss the methods used to map the deep Coral Sea, and take a virtual 3D tour to reveal the latest data and information on deep-water geomorphic features and seabed habitats. For example, the Great Barrier Reef margin forms the western boundary of the Coral Sea and is extensively cut by deep submarine canyons, or sculpted by giant undersea landslides that result in debris blocks lying within the adjacent Queensland Trough. Wherever submerged plateaus have moderately steep margins, then dense submarine canyon systems appear. Relatively flat plains and plateau tops are now observed with numerous finer-scale abyssal hills, or ridges and knolls. Surveys of individual seamounts reveal that mass wasting commonly shapes their steep flanks. This new knowledge helps to inform managers about potentially vulnerable marine ecosystems, and improves the datasets used by scientists to understand the oceanic environment. Ideas about future study areas in the Coral Sea will also be presented to help fill the data gaps and knowledge.

18E The future of the Coral Sea reefs & sea mounts
Wednesday 11 July, 1145, Sebel Kuranda

Australia's Coral Sea: how much do we know?

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The Coral Sea offers a valuable scientific reference site, as it is close to the global centre of coral reef biodiversity, without the human pressures that affect South East Asian reefs. The westward flow of major currents suggests that Coral Sea reefs act as dispersal stepping-stones between the Pacific and the Great Barrier Reef, but our understanding of these processes is in its infancy. This first comprehensive review of research conducted in Australia's Coral Sea considers almost 1 million km^2 of oceanic habitat, of which only a small portion has been studied. Out of 329 available research documents about the Coral Sea, ~25% consider the area's reefs and seamounts, which together make up ~1.2% of the total area. Research highlights include the discovery of high pelagic predator diversity, critical habitats for threatened species, deep-sea coral communities and increased knowledge of the ecology of isolated, oceanic coral reefs. Exposure and reef size are key drivers of shallow coral reef community structure. Coral, fish and invertebrate populations show key differences from the Great Barrier Reef and some affinities with reefs of the western Pacific and the Arafura and Timor Seas. Deeper Coral Sea reef ecosystems (30 - 150 m) host mesophotic coral communities that may act as refugia during disturbance events such as cyclones and bleaching. New findings are frequent, including discoveries of new species, records of coralline sponges considered 'living fossils' and high densities of predators (up to 4.4 sharks per hectare). Future protection and management options are currently being reviewed.

18E The future of the Coral Sea reefs & sea mounts
Wednesday 11 July, 1130, Sebel Kuranda

Connectivity in the Coral Sea: why should we maintain it?

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The Coral Sea is surrounded by the widest coral reef formations, the Australian Great Barrier Reef, and the world largest coral atoll lagoon of New Caledonia. Those two sites have been listed by UNESCO as World Heritage sites, in 1981 for the former, and more recently in 2008 for the later, to ensure the sustainability of those sites' integrity. A large number of other remote coral structures exist in the Coral Sea, both on the Australian and the New Caledonian sides. As those distances are large, there is however no doubt that an ecological continuum occurs at a sub-regional level. The importance of this connectivity needs today to be better investigated, especially for fishes or corals. Larvae exchanges ensure not only local reef species population replenishment, but also the genetic variability within different sites, supporting their resilience. The challenge is indeed crucial. If the connectivity is low, it means that the resilience of iosolated places is vulnerable and a suitable management plan must be implemented. If the connectivity is high, it means that intermediary reefs of the Coral Sea are acting as a genetic source for neighbouring ecosystems, linking the global resilience of the Coral Sea to their sustainability, which emphasizes even more the need for a proper management, involving at least both Australia and France/New Caledonia. Through specific examples such as finfishes, sharks or corals, we propose to analyse the general patterns of the biological connectivity in the Coral Sea and better define the next scientific challenges.

18E The future of the Coral Sea reefs & sea mounts
Wednesday 11 July, 1115, Sebel Kuranda

The color of the Coral Sea

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The Coral Sea extends more that 3000 km from about 10°S to about 24°S in the South Western Tropical Pacific. This vast oligotrophic area relates the Melanesian archipelago with Papua New Guinea and Solomons Islands at the North to the Eastern coast of Australia at the South. At around 20°S, the Coral Sea is submitted to the convergence zone of clouds and rain and exhibits a strong seasonal temperature cycle. This oligotrophic area presents everywhere a deep chlorophyll maximum and blue waters and high transparency. Average chlorophyll concentrations as detected by satellites is very low except at the vicinity of main islands and coral reefs. There, enrichments can happen at the favor of upwellings, or internal tides which can bring nutrients from the deep part of the water column. Also, during the summer season, blooms of the cyanobacteria *Trichodesmium* can enrich the surface waters over vast areas. Its nitrogen fixation can be a source of new nitrogen later assimilated by picoplankton and the marine food chain. Coastal areas show higher chlorophyll related to main land inputs, as observed in 2008 around New Caledonia. Over lagoon areas, sea color is influenced by turbidity and bathymetry. We shall present satellite and *in situ* chlorophyll data collected as part of VALidation HYperspectral of a BIOgeochemical model (ValHyBio), a PNTS-sponsored program dedicated to chlorophyll satellite imaging in the Coral Sea and validation as affected by bathymetry in the lagoon of New Caledonia.

18E The future of the Coral Sea reefs & sea mounts
Wednesday 11 July, 1230, Sebel Kuranda

A large-scale connectivity study: a Coral Sea spatially explicit ecosystem model

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The Coral Sea represents a unique ocean system, bridging the south-west Pacific Ocean environment with Australia's east marine region (specifically the East Marine Bioregion), which includes major reef and oceanographic features such as the Great Barrier Reef and East Australian Current. Conservation initiatives that cover over one million square kilometres of Australian territorial waters in the central Coral Sea have been set in place without a full appraisal of the assets and sustainable use values. Ocean spatial planning should account for the commercial and charter fisheries, tourism operators, commercial shipping and potential exploitation of the ocean in terms of mineral and energy resources. Scientific knowledge of the sea is poor, particularly the bentho-pelagic coupling in the shallower waters and around seamounts. Future management of the Coral Sea to support conservation and multiple-uses requires an evaluation of possible adaptation strategies to mitigate the impact of expected climate induced ocean changes (temperature and acidification). In this study a whole-of-system modelling framework 'Northern Atlantis' is being parameterised in order to construct a spatially explicit, coupled biophysical-geochemical ecosystem model. The model explores the role of the Coral Sea in terms of connectivity with the regional oceanographic features; linkages involving the biophysical and geochemical elements and processes. Any study should evaluate the assumption that the Coral Sea is an isolated oceanographic and geomorphic region with shallow coral reefs, deep-sea plains, seamounts and canyons. The utility of the framework in order to elucidate data priorities and provide value of information will be highlighted.

18E The future of the Coral Sea reefs & sea mounts
Wednesday 11 July, 1215, Sebel Kuranda

Aspects of deep-sea biology in the Coral Sea

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The Deep-Australia Project has investigated mesopelagic (200-1200m) and benthic (600-1200m) life in The Coral Sea and other deep sea regions over the last 3 years. This study has been conducted with a suite of new deep-sea technology including deployable cameras, traps and mid-water trawling systems, specifically designed to bring animal up alive. Results from 5 sub-projects will be presented including: the first deep-sea footage from Osprey Reef down to 1200m, zoogeography and population structure of lanternfish populations (including a unique spawning event), *Nautilus* biology and population structure, sensory biology and bioluminescence in deep-sea fish, deep-sea shark biology around sea-mounts and otherwise and comparative cephalopod sensory ecology. These observations provide some of much needed baseline data for a better understanding of biodiversity and sustainability in The Coral Sea and other waters. Two deep-worker submersibles are joining the Deep-Australia Project through a new Australian exploration company, Australian Oceanographics, and will be ready for deployment through 2012. The potential these research platforms provide will be discussed.

18E The future of the Coral Sea reefs & sea mounts
Wednesday 11 July, 1200, Sebel Kuranda

Coming, going or gone? Restricted range species on isolated islands.

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The highest rates of extinction have been in endemic species on isolated islands. In recent years, threats to coral reefs on isolated islands have increased causing both local and global extinctions. Here we evaluate the risk of extinction in four endemic and two restricted range species: McCulloch's anemonefish (*Amphiprion mccullochi*), Wide-Band anemonefish (*Amphiprion latezonatus*), Three-striped butterflyfish (*Chaetodon tricinctus*), large Doubleheader wrasse (*Coris bulbifrons*), Black cod (*Epinephelus daemelii*) and the Galapagos shark (*Carcharhinus galapagensis*) in the Australian coral reef outposts at Elizabeth/Middleton Reefs and Lord Howe Island. Effective management requires knowledge of abundance, distribution, habitat

specialisation and the level and direction of connectivity between inhabited locations of these species to determine source and sink populations. This information is essential to: 1) determine whether high abundances at Lord Howe Island will help repopulate (or recolonise) depleted populations at Elizabeth and Middleton Reef; 2) develop effective management strategies aimed at preventing these endemic or restricted range species from going extinct inside the EMMR reserve and 3) provide a baseline for future studies. Additional information on population dynamics and population structure is vital for the continued conservation of these restricted and endemic species.

18E The future of the Coral Sea reefs & sea mounts
Wednesday 11 July, 1245, Sebel Kuranda

18F Does monitoring lead to improved coral reef management?

Citizen based monitoring survey of the blue coral community (*Heliopora coerulea*) of Oura Bay, Okinawa

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A massive blue coral *(Heliopora coerulea*) community was found in 2007. It had been unknown deep under the Oura bay's water for a long time. In January 2008, 39 volunteers scuba divers have measured and estimated an approximate size of 50m long, 30m width and 14m high by using a simple method called 3 dimensional mesh method which is a modification of the ReefCheck survey method. By making a 3-dimentional map of the blue coral community, people, including non-divers, are now able to see its size, shape, and location. By visualizing those factors, local people including non-scuba divers came to have interest. In September 2009, a large scale bleaching event of the blue coral community has occured. The volunteer divers applied the 3 dimentional mesh method and found out that the degree of bleaching of the community was 45.7% instantly. The blue coral community has fully recovered from the bleaching state and returned to to a healthy state in four months. The local divers have continued monitoring and recoreding its recovery process. Comparing maps made by an expert group of geologists, WWF Japan and NACS-J, and the one that was made by the voluteer divers using only ReefCheck tools, you can see the latter map is very close to the former one. Based on our experience applying the 3 dimensional mesh method was applied to the bleaching survey, using a simple method with simple tools would be one of the keys to continue successful monitoring at the local level.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1145, Hall B

Reef-scale benthic change: using landscape mosaics to address monitoring gaps

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Coral-centric methods of reef monitoring may be significantly underestimating ecosystem decline. Unbiased monitoring of benthic reef communities is rare and traditionally requires an intensive field effort to capture the health of a reef at a moment of interest. Underwater landscape mosaics, a novel image-based coral reef monitoring and mapping technology, utilize multi-scale images of the reef benthos that are quickly acquired in the field to monitor entire benthic communities. Downward-looking images of a reef-scape are stitched together to create a single spatially-explicit image of the bottom with millimeter-scale resolution. This assessment tool was used between September 2008 and May 2010 to document and track the fate of an inshore patch reef before and after a catastrophic cold-water anomaly in January 2010. Comprehensive analysis of the benthic community showed mortality in 28%, 51%, and 36% of stony corals, octocorals, and sponges, respectively, following the cold-water anomaly. Previous studies captured the fate of only scleractinian corals following this devastating event, thereby underestimating the magnitude of total reef-decline. This study suggests that all members of sessile benthic communities are susceptible to environmental disturbance. The ability to monitor entire communities from natural and anthropogenic change can facilitate a greater understanding of coral reef communities and help support sound management decisions. In addition, the unparalleled visual record of reefal change provided by underwater mosaics is needed to support both scientific understanding and public awareness of modern reef threats at a previously unattainable scale.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1645, Hall B

Monitoring of the northern region of the Florida Reef Tract

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The Florida Reef Tract exists along the eastern shelf of the United States from the Dry Tortugas northward through the Florida Keys and southeast (SE) Florida (Miami-Dade, Broward, Palm Beach, and Martin Counties). State and county resource managers have partnered with academia to monitor the health of the northern extension of the system. Since 2000, more than 20 sites have been monitored annually offshore Broward County. Quantitative data includes stony coral species cover, colony size, density, and condition (bleaching, disease, etc.) and octocoral and sponge density. The SE Florida Coral Reef Evaluation and Monitoring Project (SECREMP) was established in 2003 and includes annual monitoring of 17 sites across the four SE Florida counties. Stony coral, octocoral, sponge, and other functional group cover collected within the SECREMP sites provides regional status and trend information. The SE Florida region typically has 2-4% stony coral cover with more than 30 stony coral species and a diverse assemblage of octocoral, sponges, and fishes. Trend analyses have shown that at most sites community metrics have remained relatively stable. Exceptions are generally sites affected by the many stressors (e.g. commercial and recreational fishing and diving, major shipping ports, wastewater outfalls, ship groundings, and coastal construction activities) to the regional ecosystem resulting from its proximity to the highly developed and urbanized coast. The coral reef ecosystem is an economic engine for the region, and the uniqueness and value of these natural resources to the community demands sustained cooperative monitoring efforts and increased investigations into limiting environmental/ecological processes.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1500, Hall B

The outlook for coral cover on the Great Barrier Reef

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The Australian Institute of Marine Science (AIMS) has surveyed coral cover on representative reefs from the Great Barrier Reef (GBR) for 26 years (starting in 1986). Sampling effort has been distributed in a design to capture the major latitudinal and longitudinal gradients of environment on a large section of shelf spanning 10 degrees of latitude (approximate area of 200,000 square kilometres). The AIMS Long-term Monitoring Project (LTMP) has used a combination of broad-scale (manta tow) and fine-scale (diver surveys of fixed transects) techniques to record changes in coral cover resolved at a hierarchy of spatial scales from sub-metre to more than 1,000 km. Over the last three decades, coral cover on the GBR has been reduced by a number of different agents including crown-of-thorns starfish, coral bleaching, disease, and tropical cyclones. The recovery of coral cover after disturbances has been tracked and full return trajectories from very severe loss states (<5% residual cover) can require decades. Some inshore areas may need even longer due to limited connectivity and/or impaired replenisment systems. Other areas have have shown robust recovery but the global picture is one of slow steady decline. Interpreting results provided by others, I will review what we know about the dynamics of coral cover at different scales and the key processes affecting coral replenishment, growth, loss and recovery. I will describe management actions taken that are intended to restore natural resilience and ask whether we could do more by way of direct action to halt or reverse recent trends.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1130, Hall B

40 years of monitoring the shape of Heron Island, GBR

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40 years of monitoring the shoreline position on Heron Island, a typical coral cay of the Great Barrier Reef, has differentiated natural perturbations related to natural cyclical events related to variations in the direction and strength of wind induced waves and recurrent ENSO weather events, from human-induced changes related to engineering works such as boat harbour dredging and building rock retaining walls to offset the consequences of sediment movement and erosion. A series of beach width measurement sites were established covering the period 1972-2012 and when combined with sequential aerial photography, provide an excellent database which enables seasonal, short term, medium

term, and long term trends in cay shape to be analyzed. Measurements of the cay's perimeter at low water indicates that it has changed little since first measured by J A Steers in 1936 even though the shave has varied extensively. This suggests that the sediment volume has remained relatively constant for the past six decades. This Coral Reef Symposium will provide an opportunity to record the location of the monitoring sites and the measurements of the beach widths for future analysis of the coral cay shape in times of climate variability.

18F Does monitoring lead to improved coral reef management?
P205

Occurrence of coral diseases in Southwestern Atlantic reefs, Brazil

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The threat that diseases pose to coral species is of great concern worldwide. In Brazil, studies of coral diseases are recent and scarce. The Brazilian Coral Reef Monitoring Program has been under way since 2002 in 6 MPAs distributed along 2,000 km (17S38W to 5S35W) of the coast and two oceanic islands (Rocas Atoll 3S33W and Fernando de Noronha 3S32W). The methodology was based on Reef Check Protocol to which gathering of more detailed data was included. From 2005 to May, 2011 a new routine was introduced in which all coral colonies were identified, counted, and recorded as healthy, bleached or diseased. Dark spot, black band, red band, white band and white plague like diseases, and tissue necrosis occurred across the whole latitudinal gradient, while yellow blotch like disease and aspergillosis, only occurred in Fernando de Noronha and Abrolhos, respectively. *Siderastrea spp*, *Mussismilia spp*, *Porites asteroides* and *Montastrea cavernosa*, the main reef-building corals of Brazilian reefs, were all affected. The higher levels of disease prevalence occurred in the northern reefs, both over the continental shelf and in oceanic islands. Therefore, low latitudes must play a more important role in diseases outbreaks that previously thought, as two of those locations are relatively protected from land based disturbances. Disease can lead to serious coral cover and diversity losses on Brazilian impoverish coral fauna. Continued monitoring is essential to determine global and local factors linked to disease outbreaks in order to implement mitigation measures on the only coral reef ecosystem in the Southwestern Atlantic.

18F Does monitoring lead to improved coral reef management?
P206

A spatial system to integrate and report reef monitoring data

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The Great Barrier Reef Marine Park Authority has a number of monitoring programs collecting valuable reef health information, gathered through various partners and other stakeholders. The monitoring programs (Reef Health and Impact Survey, Eye on the Reef Tourism, Eye on the Reef Community, and Sightings Network) have been aligned and integrated to maximise the spatial and temporal coverage of Reef health information and to enhance collective monitoring effort. Participants in the integrated program include GBRMPA staff, Queensland Parks and Wildlife Service Rangers, tourism industry, school students, recreational fishers, Traditional Owners and reef visitors. An integrated database, reporting and mapping system increases the capacity to analyse reef health status and trend data to inform management decisions to support Reef health and resilience. The integrated system strengthens early warning tools and streamlines situation reporting during environmental incidents. Tropical Cyclone Yasi provided an opportunity to evaluate the capacity of the integrated system to rapidly summarise the consequences of a spatially extensive impact on the Great Barrier Reef ecosystem. Importantly, the integrated monitoring program and system encourages stakeholder participation in monitoring and impact assessment. In addition, it provides avenues for stakeholder engagement and increases stewardship and the understanding of threats to the Reef and reef resilience. This presentation outlines the development and implementation (including TC Yasi assessment) of the integrated Reef health information system, which underpins the 'Eye on the Reef' reef health monitoring program for the Great Barrier Reef.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1515, Hall B

Brunei launches monitoring and MPA program

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Brunei is a small country located on the north coast of the island of Borneo and has historically been economically dependent upon marine based oil wells. As part of the coral triangle, Brunei has recently launched a major program to conserve coral reefs. This has included the training of 11 staff in Reef Check and other monitoring techniques, a taxonomic expedition resulting in the publication of a book on corals of Brunei, the banning of trawl fishing in most waters and the establishment of a marine protected area network encompassing most of Brunei's coral reefs. The establishment of the Reef Check monitoring program has resulted in a major increase in media coverage of the issue of coral reef conservation and has helped to build up government and public support for the new MPA network.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1115, Hall B

Community based monitoring In Lakshadweep 2001-2011: lessons learnt, challenges and way forward

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This paper draws on Socioeconomic monitoring carried out at Agatti Island, Lakshadweep in 2011 and compares it with socioeconomic monitoring carried out in 2001. The paper synthesizes data from this and a catch monitoring project to quantify and qualify human dependence on coral reefs in small islands. Data has been collected using a combination of participatory appraisal methods, interviews and surveying 400 households and 200 individuals. The monitoring carried out in 2011, shows that the matrilineal society is further breaking down, household sizes are smaller, favoring the nuclear family. 68% of the homes are owned by women as against 74% in 2001. Dependence on the reef and lagoon for food continues to grow. 90% of the households state that reef gleaning, recreation and subsistence fishing provides a source of income/food. Speargun has become popular and around 25 people use this for recreation fishing. Longline is used to catch shark. The Administration wants to regulate tourism and the Islanders want to set up resorts and home stays to augment their income. The divide between the rich and poor is growing. 94% of the people have not completed high school, showing low resilience to diversify livelihoods. These trends create challenges and reiterate the need for integrating socioeconomic with biophysical monitoring. It explains how the information is being used to encourage conservation and its usefulness to adaptive management and for developing policies for the management of tourism, artisanal and deep water fisheries, fresh water, welfare and development infrastructure.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1230, Hall B

Rapid reef health assessment by volunteers in North Sulawesi, Indonesia

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Bangka & Gangga islands are located at the northern end of Sulawesi (1°46' N 125°06' E). Currents and geomorphological features lead to the production of peculiar floro-faunistic assemblages, merging seascapes similar to those present in the Bunaken marine Park (with steep and deep walls) with those known for Lembeh Strait (with shallow volcanic sandy bottoms). The islands are also surrounded by mangroves and seagrasse meadows attended by dugongs. Unfortunately the overfishing activities well known for the area compromise a very high percentage of the reef surrounding the islands, with wide portions of damaged corals. Surveys have been performed in four sites at 6 and 12 m depth following Reef Check protocol. The sites have been selected after interviews with local people to cover the full range between heavily damaged and almost pristine sites. Comparing data it is evident that there are not differences between depths but non-impacted areas showed higher percentages of living corals and lower amount of coral rubble. The method is informative and the patchy distribution of damaged reefs suggests that prompt and effective measures of management and conservation could still allow a good level of recovery of the reef ecosystem.

18F Does monitoring lead to improved coral reef management?
P207

Monitoring as a tool to improve coral reef management

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Pohnpei is the capital state of FSM and lies approximately 5 degrees north of the equator, about halfway between Hawaii and Australia. Despite the gains in coral reef conservation and management in Pohnpei, significant gaps in understanding of the biological adequacy of the Marine Protected Areas network still exist. Several MPAs have been established around Pohnpei as a tool to mitigate human impacts on the coral reef system. Baseline surveys were conducted in 2005 with follow-up surveys and various fish spawning studies conducted from 2007 to 2010 to compare and evaluate performances of these MPAs and assess the impacts of existing management to the coral reef system. Results of these monitoring and studies identified the need for a comprehensive management plan that merges traditional measures, including size limits and gear restrictions, with precautionary management tools. Specifically, the scale and scope of MPAs should be increased to protect juveniles and other life history stages over wider areas than currently employed. Increasing evidence of reproductive migratory corridors among aggregation groupers shows the need to protect reproductive adults at and away from spawning sites throughout the spawning season. Surveys revealed a reliance on nighttime spear fishing and serranid catch composed primarily of juveniles and small adults of practically all epinepheline species. A seasonal ban intended to reduce pressure on reproductively active serranids, significantly increased the capture volume of other families. Proactive and adaptive management is needed to reduce the perceived impacts to spawning adults and juveniles and improve spawning stock biomass.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1000, Hall B

Monitoring supports establishment of Pacific Remote Islands Marine National Monument

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The U.S. Pacific Remote Islands consist of Howland, Baker, and Jarvis Islands, Johnston, Wake, and Palmyra Atolls, and Kingman Reef. Except for Wake, these islands and nearshore reefs have been administered as National Wildlife Refuges by the U.S. Fish and Wildlife Service (USFWS) as early as 1934. Before regular marine assessment and monitoring efforts began in 2000, scientists had visited these locations to collect fishes, corals, and other reef life, but few systematic reef surveys were accomplished. Since 2000, systematic inventory and monitoring surveys for fishes, corals, and benthic algae have been conducted by NOAA and USFWS during biennial cruises. Knowledge of the biodiversity, community structure, and condition of these reefs has increased dramatically because of these cooperative monitoring efforts, exemplified by the increase in number of stony corals reported at Howland from 25 to 109, at Baker from 28 to 104, at Jarvis from 0 to 70, at Palmyra from 72 to 177, at Kingman from 0 to 177, at Johnston from 38 to 49, and at Wake from 52 to 97. Informed through these survey efforts of the diversity and abundance of marine biota supported on these central Pacific reefs, President George W. Bush in January 2009 established the Pacific Remote Islands Marine National Monument to protect its historic and scientific objects. Extending 50 nautical miles from the mean low water lines of its component islands/atolls, this Monument, compared to the Refuges, provides more inclusive protection of the marine ecosystems that sustain the terrestrial, nearshore, and pelagic bionetworks.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1145, Hall B

Status of coral reefs in east and north Asia

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East and North Asian countries comprising mainland China, Hong Kong, Taiwan, Japan and Korea, lie to the north of the coral triangle of highest marine diversity. However, these reefs have been under heavy pressure of anthropogenic and natural disturbances. The coral communities and coral reefs in the mainland China are unprecedentedly degraded over the last 30 to 50 years caused by mariculture, over fishing, eutrophication, sedimentation, sewage pollution, and outbreaks of crown of thorns starfish. A grounding of a large barge was occurred in Tung Ping Chau Marine Park in Hong Kong during a storm in August 2006. It caused significant damage to the A Ye Wan core area in the marine park. The abundance of fish and invertebrate indicators at most of the sites was very low during the Reef Check survey in Taiwan in 2009. It suggested that reefs in Taiwan were under the stress of overfishing. Coral cover from 2004 to 2010 showed no significant increase in coral reef area in Japan because of the disturbances by *Acanthaster*

outbreak and typhoon. *Acanthaster* outbreaks were also observed in non reef area. Serious coral bleaching by high water temperature occurred in coral reef area in 2007. Coral bleaching was also observed in non-reef area in 2008 and 2010. In Korea, the famous soft coral beds close to the MPA in Seogwipo, Jeju Island face disturbances of port construction and land reclamation.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1030, Hall B

IUCN Reef Resilience Project: future role in reef monitoring

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Since the inception of the Global Coral Reef Monitoring Network (GCRMN) in 1996, the Network has strived to promote global coral reef monitoring, raise awareness on the current status and trends of coral reefs and provide data to assist resource managers in coral reef conservation by linking organizations and people working in the coral reef field. The IUCN Global Marine and Polar Programme has taken up GCRMN coordination at the end of 2011, with the aims to evaluate the current status of coral reef monitoring globally, and to develop recommendations and a revised strategy for the critical role of monitoring to support effective management. To strengthen the global coordination of the GCRMN, the IUCN Global Marine and Polar Programme has initiated a coral reef resilience project 'Enhancing the management relevance of reef monitoring in a changing world'. Through the compilation of a comprehensive database of high quality scientific data on the distribution and abundance of coral reefs, algae, fishes, and key invertebrates from reef sites worldwide, project findings will help elucidate the relationship between reef monitoring and management. Further in-depth analysis of global monitoring datasets can provide insight on the effectiveness of monitoring data in leading to successful management of coral reef sites. Case studies from the Caribbean and Eastern Pacific regions where monitoring data has affected management decisions will be presented and discussed.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1115, Hall B

Health assessment indexes for the coral reefs in mainland China

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Evaluation of the health of coral reefs has long been an important issue for coral reef management, identification of stress sources, and long-term monitoring of coral reefs. Many indicators have been reported, however, most of them need special techniques or monitoring protocols to get the required data for calculating the indicators. In this study, we developed four integrated indices to assess the health of coral reefs in mainland China. Our method was based on general coral reef survey data, so the indices can be calculated using widely available data. Indicators were calculated based on coral reef data of over 100 sites surveyed in 2005 and 2006, from the northern most hermatypic coral community in Dongshan, Fujian province (24 degreess of latitude) to the atoll reefs in the Xisha Islands (Paracel Islands, 16 degrees). Then three integrated indices, namely a basic health index, a community structure index, and a stress index respectively, were developed as the weighted sum of those indicators. The basic health index mainly consisted of coral coverage, species richness and diversity indices; the community structure index and the stress index was composed of the proportion of different species and substrates such as sand and silts. The comprehensive index was simply the sum of three integrated indices. Key to understanding the indices was: the indicators were transformed into unitary indicators; and the weights were obtained via the principal components analysis technique to guarantee the unitary and objective feature of the indices.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1200, Hall B

Beyond the biophysical: establishing a long-term socioeconomic monitoring program for the United States' coral reefs

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NOAA's Coral Reef Conservation Program supports effective management and sound science to conserve coral reefs, with a majority of effort focusing on the seven U.S. states and jurisdictions with coral reefs: American Samoa, the Commonwealth of the Northern Mariana Islands, Florida, Guam, Hawai`i, Puerto Rico, and the U.S. Virgin Islands. While the Coral Program has been successfully monitoring biological and physical health of coral reefs since its inception a decade ago, we've neglected to do the same for socioeconomic factors. There are no social, economic, or cultural indicators that the program tracks on a consistent basis to measure change over time or in a way that allows comparisons among jurisdictions. Beginning in 2013, the U.S. National Coral Reef Monitoring Program will

measure a suite of indicators to answer the key monitoring question: 'How are human uses of, interactions with, and dependence on coral reefs changing over time?' This decision represents a strong step forward for NOAA's Coral Program, which has recognized the need to integrate socioeconomic factors with our suite of biophysical indictors, but has struggled with operationalizing this change. This presentation will share the indicators that we'll be tracking, our methods for doing so, and some initial data collected from Saipan and the Virgin Islands. Questions, advice, and criticism will be welcome from the audience.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1245, Hall B

A long term experiment in the Coral Coast MPA, Brazil

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This paper reports the substantial changes that took place in the reef community structure of a coral reef system in the Brazilian northeastern coast after 12 years of cessation of all kinds of exploration and tourism activities. In 1999, an area of 400 ha, 1.5 km off the coast of Tamandaré, including several reef habitats, was fully protected in order to carry out comparative reef recovery experiments. Community based surveillance has been maintained throughout the whole process to guarantee no direct human interference in the experiment. Fish assemblages and benthic communities were monitored using diving techniques and, more recently, a real-time on-line stationary underwater video system was implemented. Monitoring was also conducted in adjacent open reef areas for comparison. Comparative results showed that in the fully protected area a progressive and substantial increase in diversity and abundance of reef fish, lobster, octopus, branching hydrocoral coral cover, and a decrease in sea-urchin abundance and reef bio-erosion rates occurred, leading to a much better overall reef health condition, when compared with adjacent open reef areas. This long term experiment was decisive to the ongoing implementation of a network of spatially connected small fully protected reef areas along the Coral Coast MPA. Results showed that this strategy can be an efficient management alternative for the conservation of Brazilian coral reefs, especially in areas of multiple use where large protected areas can induce user conflicts and where enforcement, the most important factor for success, is often financially and logistically prohibitive.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1715, Hall B

Investigation and adapting ecological effectiveness for community-based management in Fiji

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The Fiji Locally Managed Marine Area (FLMMA) Network have recorded more than 200 marine managed areas (MMA) through the set up of tabu area in Fiji since establishment in 2000. The Conservation International Marine Managed Area Science (CIMMAS) program was tasked to examine the efficacy of management regimes in protected and managed near-shore coral reef habitats through detailed data collection and analysis, and utilize those data and results to illuminate the ecological processes driving coral reef resiliency. Four MMAs were selected, each with differing investment in management and environmental characteristics and assessment design considering protection status and depth. Ecologically benefits are accruing within the no-take tabu areas within the MMAs studied - across all sites in which the tabu area remains there were significantly greater targeted fish biomass. The results are inconclusive over the effects of protection on the status of the wider ecosystem. At the only site at which treatment-control could be established, data were not able to conclusively prove the presence of benefit beyond the boundary of the no-take tabu area. However a number of emergent themes need to be addressed in order to continue these successes. These themes are communities entering a capital society-monetizing fisheries, receiving fisheries benefits that threaten the long term existence of many of the MMAs in Fiji, developing an integrated national plan for MMAs and the role of MMAs in fisheries sustainability at the national scale.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1130, Hall B

Two hundred eyes are better than two

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In June 2007 the Great Barrier Reef Marine Park Authority launched the expansion of the Eye on the Reef Monitoring Program, thus creating the largest tourism-driven coral reef monitoring program of its kind. This was

achieved through a strategic partnership between the Great Barrier Reef Marine Park Authority (GBRMPA), 40 high standard eco-certified Great Barrier Reef tourism operators and a group coral reef researchers. This partnership continues to be based on vested interest in the health of the Great Barrier Reef. It has created a large network of regular Reef visitors, trained in standardised monitoring methods, recording information on the biology of multiple sites along the Great Barrier Reef, simultaneously. The Eye on the Reef Tourism Monitoring Program, now in its 14th year, involves over 45 operators and 130 trained tourism staff, along the Great Barrier Reef from Port Douglas, Lizard Island, Cairns, Townsville, Magnetic Island, the Whitsundays, Bowen, the Keppels, Lady Elliot Island and Heron Island. The Sightings Network, under the umbrella Eye on the Reef Program, contains 6,000 records of sightings from over 200 locations along the Great Barrier Reef. The Eye on the Reef Program provides management with observations and data, from multiple sites and has proven to be a necessary information source post extreme weather events.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1015, Hall B

Coral reef temporal changes at Twin Rocks Fish Sanctuary, Philippines

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This study aims to examine the present status of the coral reefs in Twin Rocks Fish Sanctuary, Batangas, Philippines and the temporal change in terms of fish abundance, and percent live coral cover from 1993 to 2011. Point intercept transect method and analysis showed that there was a 152.13% increase in percent live coral cover from 1993-2011 inside the sanctuary. Line intercept transect method and analysis showed that there was an increase of 54.51% inside the sanctuary and a decrease of 1.19% outside the sanctuary from 2000-2011. For fish abundance, there were 946.5 individuals/500m^2 in 2000, whereas there were 1084 individuals/500m^2 in 2011; a 14.58% increase inside the sanctuary. Outside the sanctuary, fish count showed there were 1769.5 individuals/500m^2 in 2000, whereas there were 556.5 individuals/500m^2 in 2011; a 68.5% decrease. Further, the number of fish families identified and counted inside the sanctuary remained stable at 26-27 while there was a decrease of 30.77% outside the sanctuary. The results imply that protection is effective in increasing percent live coral cover and fish abundance inside the sanctuary; however, these increases are not sufficient to warrant increase in fish abundance outside the sanctuary and fish catch near the sanctuary. Fisher interviews showed that there was an indicative decrease in the overall fish catch from 1993 to 2011. Also, a 96% increase in number of scuba divers in the sanctuary from 2000 to 2011 poses threat to the overall health of the reef. Further monitoring and evaluation using adaptive management framework is recommended.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1630, Hall B

Status of *Acropora* populations in Central and Southern Mexican Caribbean

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Due to the ecological importance of the corals *Acropora palmata* (AP) and *Acropora cervicornis* (AC) in the Caribbean, and the reduction of their populations in the last decades, these species are subject to special protection under the CITES convention and as threatened species under Federal Laws in Mexico. However, even under special protection the actual status of their populations is unknown in the Mexican Caribbean. The objective of this project was to generate information on the location and status of the populations in the central and southern mexican and desing, if needed, restoration projects for affected areas. The identification and delimitation of *Acropora* sites was done using aerial photography and underwater asessment in the potential areas of distribution. Patches were delineated in polygons and their location represented on maps of the area. We selected 25 sites of *Acropora* patches with living colonies to assess the condition by taking measurements of height and maximum diameter, and estimates of % of mortality, bleaching, disease and other NOAA health condition indicators. For AP, 5% registered sign of diseases, 15% presented predation by damselfish and aproximately 45% of the colonies evaluated were overgrowing old *Acropora* skeletons which could be a sign of recovery. With these results we selected populations that may serve as donnors and potential restoration sites. The detailed physiographic and biological characterization of the sites is of great importance related to management and conservation of the species, and essential to initiate programs to restore the species in the Mexican Caribbean.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1245, Hall B

Currently turning to coral monitoring and management by climate changes in Korea

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As we previously reported Korean waters do not possess typical coral reefs based on reef building stony corals. However, in 2001 we recorded, as part of the MPA program, some kinds of hard corals (*Favia sp*.) around the southern parts of Jeju Island. But now, by climate changes, tropical biota recruited massively passing the time in all area including the sea. Corals also designated to the target species observing climate change in Korea. Octo-corals including soft corals about 138 species identified in Korea. Most of them, it have distributed in the southern sea including Jeju Island. Now, nevertheless total of 21 species of stony corals identified recently. Before, we focused on the soft corals research such as bio-geographical study, spatial distribution and densities mainly considering to the coastal development to expand the port and land reclamation. But now, we have turning to the point of our interests affected the corals to environmental effects, because the climate changes effects face to coming rapidly in Korea waters. We are now ready for the management program, focused on corals and other endemic species immigrated by tropical waters from 2010.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1745, Hall B

Coral reefs of Gulf of Mannar, India- signs of resilience

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The coral reefs of Gulf of Mannar (GoM) experienced severe degradation during 1980s and 90s primarily due to rampant mining and destructive fishing. The coast is densely populated and the health of reef environment is also affected by sewage discharge. Nine distinct coral disease types were recorded and its prevalence increased from 6.9 ±1.7% in 2007 to 10.3±1.6% (mean ± SD) in 2010 ($p<0.0001$). However, the reefs of GoM exhibit signs of resilience, especially since 2005 after coral mining was halted and with a reduction in destructive fishing activities. The live coral cover increased from 36.98±13.12% in 2005 to 42.85±10.74% (mean ± SD) in 2009. Coral mortality due to elevated sea surface temperature and bleaching reduced live coral cover to 33.20±10.23% (mean ± SD) in 2010. An estimated 9.99% of coral colonies bleached, and less than half of these recovered. Steady recovery in 2011 increased the live coral cover to 37.31±10.38% (mean ± SD) ($p= 0.0315$). This was in part due to recruitment, with recruits relatively unaffected by bleaching, along with recovery of partially dead colonies. Coral recruit density in 2005 was 0.41±0.58 per m^2 and 0.78±0.87 per m^2 (mean ± SD) in 2011 ($p= 0.9591$). Continuous monitoring, timely management action, awareness and capacity building and enforcement hold the key to sustaining reef resilience in GoM.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1215, Hall B

From data to improved conservation: success stories in Madagascar

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Most of Madagascar's 3,934 km² coral reefs occur predominantly as emergent fringing, barrier and patch reefs in the northeast, northwest and southwest. Since 2002 reef health assessment studies, using GCRMN protocol, have been conducted on 67 stations around Madagascar by Wildlife Conservation Society scientists. The results vary depending on the location of each station but the overall trend shows that the inner reef flat is being degraded with a rate of coral mortality over 65%, while the outer slope exhibits a high percentage hard coral cover from 35 to 60% and supports relatively healthy fish communities with a mean biomass of 978 kilograms per hectares. These data were used to guide the development of a national marine protected area network which is underway in Madagascar with sixteen new marine protected areas under temporary or permanent protection in 2010. In addition, for the last 10 years a coral reef monitoring program is ongoing in the northeast to assess the management effectiveness of three national marine parks along Masoala peninsula. Although fish biomass is greater inside these protected areas than outside, the main temporal trend is a decrease in fish biomass because of a lack of compliance. In the process of updating the management plans of these marine parks a community workshop was held in 2011 during which monitoring results were shared and discussed. Main outputs were the decisions by the local community to increase the amount of

productive areas included in no-take zones and to strengthen enforcement.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1530, Hall B

Securing a future for endangered corals

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Ocean acidification is one of the greatest overarching concerns in the marine environment and coral reef ecosystems are extremely vulnerable. The emerging science on ocean acidification should inform management decisions and policy considerations when it comes to ocean health and resources. We will discuss how science can bring ocean acidification into the forefront of environmental policymaking and ecosystem management. Ocean acidification must become an important policy consideration driving local, national and international efforts to reduce carbon dioxide emissions. The presentation will highlight how existing water pollution laws can be brought to bear to address ocean acidification. We will discuss how under the U.S. Clean Water Act the government has the ability and the duty to regulate carbon dioxide pollution that is causing ocean acidification. Specifically, we will explain new developments that can improve water quality monitoring and assessment for ocean acidification and management of coral reefs. We will also discuss how protecting corals as endangered species can promote their conservation and recovery. In April 2012, the United States made a determination about whether 82 corals should be listed as threatened or endangered. We will present about what this landmark decision means for protecting coral reefs from a variety of threats ranging from overfishing and pollution to ocean acidification and climate change.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1730, Hall B

A quantitative SocMon approach for fishing communities in northern Honduras

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Sound policy decisions in coastal areas require that coastal managers have objective and timely information on the socioeconomic and environmental impacts of the policy and program alternatives being considered. Effective decision making also calls for periodic assessments of the impact of socio-economic and environmental conditions in order to identify the fishery activities, coastal communities, and families experiencing economic stress. In this paper we used socioeconomic variables to generate sets of socioeconomic and environmental models based on realistic policy scenarios and provided these to coastal managers in order to inform their decision making processes. Data from the 2011 socioeconomic monitoring (SocMon) survey in the Northern Coast of Honduras are used to develop a series of interacting rural household models nested within a general equilibrium model of eight fishing communities. Our approach captures the heterogeneity that characterizes the communities in coastal areas in developing countries, where fisheries and other economic activities, technologies, factor endowments, and income sources vary widely across the different fishing communities and groups. Our approach explicitly takes into account the wide diversity of economic activities in which individual fishing households may be engaged, including (depending upon the context) the kind of fishing, tourism, and agriculture present, as well as the changes in human population densities, migration patterns, and other activities. Fishing households engage in a variety of economic activities and use diverse technologies. The models are quantitative inputs for the current SocMon monitoring system and is developed together with our counterparts in the north shore of Honduras.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1230, Hall B

Science-based design of coral protected areas in the Gulf of Mexico

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The Flower Garden Banks National Marine Sanctuary (FGBNMS) contains the northernmost coral reefs in the continental United States, part of a discontinuous arc of topographic features located along the outer continental shelf margin in the northwestern Gulf of Mexico. The coral reefs here are among the healthiest in the western Atlantic and Caribbean region, in spite of being located within one of the most intensely developed offshore oil and gas exploration regions in the world. Based on a recent management review, FGBNMS proposes to expand the sanctuary to include at least nine additional reefs and banks, in order to provide increased protection to coral communities and associated mesophotic habitat. To accomplish this, FGBNMS worked extensively with the public through a citizen-based advisory council, consisting of

representatives from fishing, diving, oil and gas, research, education, and conservation groups. The goal was to design a network of marine protected areas that while large enough to provide essential protection for fragile marine resources, would minimize the impact on the activities of a variety of user groups. The design methodology was based on information derived from over 30 years of science, monitoring and resource management of the region. Base maps of all subject areas were developed utilizing high-resolution multibeam bathymetry. Primary habitats were characterized based on direct surveys and predicted habitat suitability. Core biological areas were delineated and a variety of buffer areas were considered. The resulting proposal balances the need for protection while allowing for appropriate resource utilization.

18F Does monitoring lead to improved coral reef management?
Thursday 12 July, 1700, Hall B

Socio-economic monitoring improves adaptive management planning for Helen Reef, Palau

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Helen Reef Resource Management Program

Over the last 10 years, Helen Reef Atoll in the remote Southwest Islands of Palau, Micronesia has been designated as a marine protected area. Prior, Helen Reef was often the target of authorized foreign fishing vessels from nearby Philippines and Indonesia. Marine resources of specific species were also threated by overharvesting from local residents. After a three year no-take moratorium that ended in 2004, a community planning process was completed which took into account various spatial, biological and social factors in the planning of new zones and rules for the overall management of the site. A community consultation effort allowed for various input on customary uses, traditional knowledge, and economic values related to the site. The resulting multiple-use management plan was acceptable to the local community while attempting to incorporate design features to ensure the long-term sustainability of various resources and habitats. Socio-economic monitoring for the site was initiated in 2008, with a baseline assessment examining local uses and values related to the site. General satisfaction of management and recommendations for improvement were also examined. The results of this assessment proved useful in a recent 10 year review and update of the Helen Reef Management Plan, which led to a better management arrangement and sharing of benefits among the local resource-owning community. Revisions in the management plan also provided for improved efficiencies in management, resilience, and enforcement strategies.This paper will describe the outcomes of monitoring efforts and how they have lead to improved management at the site.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1200, Hall B

A socio-economic assessment: risks, hazards, climate change impacts and adaptation at a local level

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Managing risks from extreme events will be a crucial component of climate change adaptation. We demonstrate an approach to assess future risks and hazards and prioritisation of adaptation options from the local scale. Existing tools including SocMon climate change addendum, cristal, vulnerability assessment framework etc. are integrated and employed at a local scale to assess social vulnerability of coastal people and their livelihood systems to climate and other threats focusing on vulnerability to short-term seasonal risk. The study demonstrates that natural conditions and the local knowledge provide both constraints and opportunities for local communities. Historical responses to climate events were based on predictability of events were more reliable, this was important for food security and livelihoods. Results show that without sufficient adaptation measures this community will more likely suffer negative impacts varying widely by the kind of impact on the respective livelihoods. By incorporating local knowledge and strategically developing a multi-stakeholder process in which the community is fully engaged and takes the lead, will make them more likely to initiate and actively participate in sustainable adaptation activities and projects.

18F Does monitoring lead to improved coral reef management?
Friday 13 July, 1215, Hall B

Theme 19. Human impacts on coral reefs

19A Human impacts on coral reefs

Does capacity building and community engagement improve the protection of near-shore coral reefs?

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Successful conservation of coral reefs will depend on the leadership and capacity of communities that depend on marine resources for survival. This is particularly true in the Coral Triangle, where reefs provide critical resources for millions of people in near-shore fishing communities. We worked with local leaders in Indonesia and the Philippines to implement social marketing techniques at 26 sites where destructive fishing practices were having a significant impact on coral reef communities. Each leader designed and implemented a social marketing campaign to foster buy-in and compliance with local laws and reduce destructive behaviors. Qualitative and quantitative research techniques were used to develop a behavior change strategy and key messages, select strategic channels, and identify trusted sources, to implement a social marketing campaign that targeted specific segments of the population. Impact and results were measured through Knowledge, Attitude and Behavior Change surveys for each target population (sampled at 5%CI and 95%CL). Our research suggests that social marketing implemented by local leaders can be an effective tool for reducing destructive fishing practices and building constituencies for coral reef conservation. In many cases, significant increases in knowledge and attitudes were associated with decreases in destructive fishing practices and support for marine protected area enforcement. We will discuss the challenges and opportunities in building community capacity for coral reef conservation as well as highlight the value of implementing a robust monitoring and assessment plan for measuring social as well as conservation impacts.

19A Human impacts on coral reefs
Tuesday 10 July, 1645, Sebel Kuranda

Interpretation to manage marine recreational resource use in Kenya

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The ultimate goal of natural resource management is for the resource users to engage with the resources in an environmentally responsible manner. Interpretation (defined as creating awareness regarding the natural resources and how to interact sustainably with those resources) is one tool that can be used to influence the actions or inactions of resource users, and thereby manage the resources. An understanding of behavior and behavior change can guide interpretation efforts so that they are effective in influencing behavior. This research project proposes to use underlying behavioral principles to determine the most effective interpretive messages and then test the efficacy of this interpretation in recreational marine resource users (snorkelers and scuba divers) in the Mombasa Marine Park. Three types of data will be collected: data from visitors prior to their excursion will reveal their behavioral intention (questionnaire), monitoring data of their behavior whilst in the water, and subsequently data about their experience (questionnaire). These data sets will be collected for different visitor groups that have received differing amounts and differing types of interpretation. These three data sets that span these different groups will provide useful information in determining: a) do visitors actually behave as they intend to behave b) how effective are interpretive methods and what parts of the behavioral process are they targeting (attitudes, norms, control factors), and, c) can visitor experience be used as an indication of pro-environmental behavior.

19A Human impacts on coral reefs
Tuesday 10 July, 1030, Sebel Kuranda

Monitoring of marine protected areas and resilience of coral reefs

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We examined the relative roles of human impacts on corals in Jamnagar, Gujarath in west coast of India. The diversity, frequency, and scale of human impacts on coral reefs are increasing to the extent that reefs are threatened due to industrial activity such as construction of ports. Projected increases in industrial activities over the next 30 years exceed the conditions under which coral reefs have flourished over the past half-million years. However, reefs will change rather than disappear entirely, with some species already showing far greater tolerance to climate change and coral bleaching than others. We transplanted sixteen types of corals and observed growth. Marine protected areas (MPAs), as a management strategy that supports reef resilience need to be vigorously implemented, and complemented by strong

policy decisions to reduce the rate of human impacts and industrial activities. MPAs are aimed at managing and protecting marine environments. Their design, however, often disregards both a thorough knowledge of the distribution of habitats and assemblages and the use of proper experimental evaluations of the efficacy of MPAs by comparing protected vs. unprotected zones. We propose the use of experimental procedures generally utilised for detecting environmental impacts. The aim of this paper is to show that, at least in the west coast of India, the effectiveness of MPAs has been rarely demonstrated because of lack of appropriate sampling designs. Intertidal coral transplantation was success. An MPA can be considered as a zone subjected to human impact, presumably a positive one.

19A Human impacts on coral reefs
Tuesday 10 July, 1630, Sebel Kuranda

Fish feeding inside Brazilian MPAs: impacts on reef fish community structure

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Although the practice of feeding fish by tourists is widespread within Marine Protected Areas (MPAs), the ecological consequences of this activity have received little attention. This research aimed to investigate the influence of artificial feeding on reef fish communities of two Brazilian MPAs. Visual censuses were performed in areas not visited by tourists, in order to characterize the natural community structure of each reef system. In Maracajá reefs, the effect of artificial feeding was assessed below a moored pontoon found in the area. Stationary visual censuses were carried out before, during and after the fish feeding activity. In Maragogi reefs, research areas with presence and absence of tourism visitation were established. Transect methodology was employed in each of these areas. In both MPAs, fish feeding was a formal activity and occurred on a daily basis during the course of this study. Within the MPAs, 88 species belonging to 40 families were recorded. In Maracajá, fish, shrimps and squids were provided by the tourists on the pontoon, which favored mobile invertebrate feeders, whereas in Maragogi, animal ration and human food were used, causing aggregations of omnivores. Differences were observed in terms of abundance before and after feeding in Maracajá and between control and impacted areas of Maragogi. The data are consistent with fish feeding leading to attraction of determined species, causing an increase in their abundance, also indicating that both the type of food and the extension of activity area are important factors determining the effects on fish communities.

19A Human impacts on coral reefs
P209

Synergystic effects of bleaching and dredging on coral reefs

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The Montebello/Barrow islands (MBI) are situated in the Pilbara Offshore marine bioregion (IMCRA, 1997) approximately 1,600km north of Perth. The marine ecosystem of the MBIs have remained in a relatively undisturbed condition due to the low human usage and strict management controls on industry activities in the area. The Gorgon Project (GP) which is based on Barrow Island is the largest single natural gas project in Australia's history. The GP includes the construction of a 2.1km marine offloading facility and a 2km jetty (total length 4.1km) requiring a dredging program that will involve the removal and dumping of ~ 7.6 Mtonnes of marine sediment over a period of approximately 18 months, from May 2010. The environmental approval for the GP included an assessment of the potential impacts of the dredging on coral reef communities over the broader scale of the MBIs. In late January 2011 a coral bleaching event resulting from high water temperatures was recorded throughout the MBI MPAs including the reefs that have been subject to increased suspended sediments as a result of the dredging program. Monitoring of a range of coral communities within the MPAs prior to, during and following both the bleaching and dredging events provides us with some indication of the short term synergistic impacts of these two pressures that have been identified as important for the long term survival of coral communities within the MPAs.

19A Human impacts on coral reefs
Tuesday 10 July, 0945, Sebel Kuranda

Climatic and anthropogenic drivers of river runoff in northeast Madagascar

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Rivers and their associated watersheds govern the erosion and transport of terrestrial material into the marine environment. In order to characterise the impact of terrestrial runoff on a large tropical embayment in Madagascar, we analysed the skeletal properties of giant corals spanning the past 300 years. By combing spectral luminescence scanning and geochemistry data we decouple 20th century human deforestation effects from rainfall induced soil erosion. Not only do the corals provide the first evidence for Pacific decadal modulation of rainfall over the western Indian Ocean, they highlight the impact of deforestation. Since the mid-20th century when deforestation was highest, erosion has accelerated at a fast rate post-1980. To investigate the driving mechanisms behind this recent acceleration of river discharge and sediment runoff, we used the hydrological model STREAM and the sediment model N-SPECT, based on precipitation and temperature trends, elevation, land-cover and soil water storage capacity data for the region. On annual time-scales, changes in precipitation, river discharge and sediment yield significantly explain the variability of runoff proxies in the respective region. However, results suggest that while precipitation steers the delivery of sediment and pollutants through discharge, deforestation and human population growth are the underlying drivers of the recent acceleration.

19A Human impacts on coral reefs
Tuesday 10 July, 1015, Sebel Kuranda

Potential endocrine disruption in fish from the Great Barrier Reef region

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The potential impacts of endocrine disrupting compounds, including triazine herbicides, on wild fisheries populations have not been assessed. In the Great Barrier Reef (GBR) region such impacts are likely to be high given that: (i) low chronic levels of herbicide residues are present in the GBR throughout the year(ii) triazine concentrations exceed GBR and national water quality guidelines in some freshwater and marine locations, and (iii) labile sex determination is common amongst tropical fish. We hypothesize that exposure to atrazine, an estrogen mimic, may result in endocrine disruption in native fish species, particularly in species that are sequential hermaphrodites. Here, we test the prediction that such exposure in the wild may result in altered patterns of gene expression. We collected juvenile (putatively male) barramundi (*Lates calcarifer*) and juvenile (putatively female) coral trout (*Plectropomus leopardus*) across the GBR region during the 2011 wet season. Expression levels of two genes, vitellogenin (egg yolk protein which is normally expressed only in sexually mature females) and aromatase (converts testosterone to estrogen and is linked to sex change), were measured on liver, gonadal, and brain samples via qPCR. Our initial results do not indicate altered gene expression in juvenile coral trout collected from the reef. However, we see frequent up regulation of vitellogenin in barramundi collected from freshwater and estuarine wetlands, suggesting the potential for wide spread exposure to endocrine active compounds. We discuss our results in the context of potential implications for wild barramundi fisheries, and make recommendations for future research.

19A Human impacts on coral reefs
Tuesday 10 July, 1130, Sebel Kuranda

Characterizing harmful behaviors of divers and snorkelers to coral reefs in Puerto Rico

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We report preliminary results from a study into the recreational misuse of coral reefs in Puerto Rico. Our first objective was to establish baseline data on harmful behaviors of divers and snorkelers to reefs. Such baseline data are necessary in order to evaluate the effectiveness of strategies to influence the behavior of visitors to reefs. We gathered data via direct observations of tourists in the water. Self-reports of behavior were also collected post trip. We report on the accuracy of self-report data. Our second objective was to experiment with influencing behavior. We did this by developing a multi-media presentation that operators require visitors to view before going to the reef, by having tourists sign a pledge to not touch the reef, and by giving tourists underwater fish cards that also contain positive behavioral reminders. This three-pronged intervention is based on theories of environmental behavior. Our third objective was to assess the effectiveness of the interventions at changing behavior. We did this by repeating the data-collection protocol used in the first objective and then comparing rates of contact with coral by visitors who viewed the message with the baseline data. Although the proposed work focuses on Puerto Rico, the results will be useful to many political jurisdictions and will provide badly needed knowledge necessary to make progress on the #1 priority goal listed in NOAA's Coral Reef Conservation Program: To improve and maintain resilience of coral reef ecosystems

and the human communities that depend on them.

19A Human impacts on coral reefs
Tuesday 10 July, 1745, Sebel Kuranda

Does collecting inhibit the recovery of anemone and anemonefish populations after a bleaching event?

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The unique, obligate association between anemones and anemone fishes and their aesthetic appeal make these species vulnerable to commercial exploitation, particularly because they are so easy to collect. In the Keppel region of the southern Great Barrier Reef, a moratorium on the commercial collection of some species of anemone and anemone fishes was undertaken in 2007 by commercial collectors in response to concerns about the impacts of a thermal stress event in 2006. The moratorium specified that there would be no collection of the anemonefish, *Amphiprion melanopus* or the sea anemone, *Entacmaea quadricolour* in the region. Collection of *Amphiprion akindynos* and the solitary sea anemone *Heteractis crispa* continued at all sites except three. Surveys of these four species were conducted at five reefs before and after the implementation of the moratorium to investigate the influence of collection on recovery of the populations. Densities of *E. quadricolour* increased at all sites but *H. crispa* was not found at any sites during the study. *A. melanopus* was found at only four out of five sites. The density of *A. melanopus* increased at three out of five sites and decreased at the remaining site. The density of *A. akindynos* increased at four out of five sites but decreased at the only site that remained open to collecting. These results suggest that the populations of some species of anemones and anemone fish in this region may be recovering from the impacts of the 2006 bleaching but that collecting pressure could be inhibiting this recovery.

19A Human impacts on coral reefs
Tuesday 10 July, 1515, Sebel Kuranda

Fate of re-suspended dredge material at Apra Harbor, Guam

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Model studies have been conducted to investigate the potential coral reef exposure from proposed dredging associated with development of a new aircraft carrier berthing site in Outer Apra Harbor, Guam. The Particle Tracking Model (PTM) was applied to quantify the exposure of coral reefs to material re-suspended by the dredging operations at three proposed sites. Key PTM features include the flexible capability of continuous multiple releases of sediment parcels, flexible control of parcel/substrate interaction, and the ability to track vast numbers of parcels efficiently. This flexibility has allowed us to simulate the combined far-field effects of clam shell dredging, of chiseling to fracture limestone blocks, of silt curtains, and of flocculation. PTM was also used to model the fate of hypoxic water released during dredging. Because the rate of material released into the water column by some of the processes is not well understood or a priori known, the approach chosen has been to bracket parameters within reasonable ranges to produce a suite of potential results from multiple model runs. Data analysis results include mapping the time histories and the maximum values of sediment concentration, sediment deposition, and hypoxic water dilution. The next phase of the analysis will be an ecological assessment to translate the PTM exposure level predictions into predicted amounts of coral reef damage. The level of potential coral reef impact will be an important component of the final selection process for the carrier berthing site.

19A Human impacts on coral reefs
Tuesday 10 July, 1500, Sebel Kuranda

Surface sediment composition as an indicator of sedimentation stress and nutrient level in coral reefs

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Surface sediment composition (i.e. particle size and organic matter) has been widely used to trace terrestrial inputs into river mouths, bays and oceans. However, this approach has rarely been used in coral reefs. This study examined the spatial composition of surface sediment and its relation to sedimentation rates, nutrient levels and coral community composition in Sanya coral reef reserve, where coral communities are known to have been significantly impacted by sedimentation. The results demonstrated that surface sediment composition showed a clear spatial gradient, which was consistent with sedimentation rates and nutrient levels. The organic matter (OM) of surface sediment was positively correlated with sedimentation rate ($p = 0.04$ for 0-2000 μm and $p = 0.008$ for 0-63 μm) and nutrient level (i.e. delta 15N from *Turbinaria ornata*) ($p = 0.009$). The silt-clay size (0-63%) of surface sediment was also positively correlated with nutrient levels ($p = 0.022$). The results suggest that OM,

silt clay size and terrestrial inputs were closely related to coral community composition in Sanya. We conclude that surface sediment composition (e.g. OM and silt clay size, 0-63%) could provide a rapid and reliable indicator of sedimentation stress and nutrient level in coral reefs.

19A Human impacts on coral reefs
Tuesday 10 July, 1000, Sebel Kuranda

Submarine cable impacts on benthic communities in Bermuda

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As renewable energy technology (e.g. wind, wave, tidal and currents) develops, more man-made structures including associated cabling systems will be placed into the marine environment. Some of the greatest impacts from the installation and operation of cables are on benthic habitats (e.g. damage to organisms and seabed, increased noise, introduction of hard substrate, changes in circulation and currents, electromagnetic fields and thermal radiation). Achieving maximum renewable energy benefits with minimal detrimental effects to benthic habitats is a challenge, especially given the dearth of studies. Here, existing (70 years old) submarine power cables and a proposed submarine power cabling project in Bermuda provided an unique opportunity for insight into the effects of cabling systems on benthic habitats. The objectives were to determine and document the cumulative observable impacts of the existing submarine cables on the benthic habitats and to determine best ways to mitigate effects for the proposed new submarine cables. In September 2008, the existing cables and the proposed routes for the new cables were assessed *in situ* with species and habitats photo-documented and inventoried. Not surprisingly, the main observable impact for existing cables was the introduction of hard substrate resulting in an increase in species richness in sea grass habitats. The coral, *Siderastrea sp.* was the most commonly observed recruit on the existing cable. As expected seagrass beds and patch reefs appeared to be more impacted than the soft sediment habitats. Implications of increased submarine cabling with suggested best practices and directions for future research will be discussed.

19A Human impacts on coral reefs
Tuesday 10 July, 0930, Sebel Kuranda

Relating molluscs species traits to environmental variables in marginal reefs

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Habitat destruction, pollution, exploitation of living resources, climate change and other human activities are adversely affecting the biodiversity of ecological communities around the world. In eastern Australia, subtropical 'marginal' reefs are increasingly subjected to stressors from human activities and climate change. Moreover, there is a lack of studies that directly assess how human settlement patterns affect coral reefs. Here I use molluscs to assess what are the environmental drivers of changes in the marine community in Moreton Bay Marine Park (Queensland, Australia). The area provides habitat for an extraordinarily large number of marine molluscs with over ~900 species of gastropods alone. Molluscan fauna are good bio-indicators of environmental conditions and useful as indices of local abundance and community structure. The research used micromolluscs to identify associations between species traits and environmental variables in order to understand the causes of ecological changes in the communities and to predict whether species with given traits will persist under changing environmental conditions. We used RLQ analysis, an ordination technique to assess relationships between traits ande nvironmental conditions particularly in relation to disturbances. We identified environmental gradients associated with significant variation in species traits from urban-impacted areas, to marginal reefs reflecting high turbidity and variable nutrient conditions and tidal flats reflecting optimal conditions for zooxanthellate organisms.

19A Human impacts on coral reefs
Tuesday 10 July, 1115, Sebel Kuranda

Impacts of marine debris on sea turtles

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Marine debris ingestion is a major problem for sea turtles, resulting in both lethal and sublethal impacts. Over 30% of turtles stranded between 2006-2010 in the Moreton Bay region of Australia were found to have ingested marine debris. In other regions, up to 100% of stranded turtles have been found to contain plastic within their digestive system. However, these figures may not adequately represent the true magnitude of the problem. In order to accurately assess the risks to turtles we need a better understanding of the dynamics of the interaction between sea turtles and the debris that they consume. We investigate the

selectivity of sea turtles with regard to the ingestion of marine rubbish, particularly focusing on plastics. We have compared the colour and consistency of plastics found within the gut of stranded green sea turtles sourced from the Moreton Bay region to that 'available' in the environment, as measured by regular beach surveys. Results indicate that turtles do exhibit a preference for particular types of debris. To understand why this might be the case, we use a spectrophotometer to measure the optical characteristics of plastics, and how they would appear to a turtle. We compare this with the optical characteristics of typical food sources for green sea turtles. Results are discussed in relation to the visual anatomy of sea turtles, and we make preliminary recommendations for ways to reduce the impact of marine debris on sea turtle populations.

19A Human impacts on coral reefs
Tuesday 10 July, 1730, Sebel Kuranda

The importance of heterotrophic adaptations of corals to maintain energy reserves

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The naturally high terrestrial run-off and river loads, plus the ongoing coastal developments and increasing human impacts, make the area of Bocas del Toro, Panama, a suitable research area to investigate long term adaptation processes of scleractinian corals to atypical coral environments, and additional short term acclimatization processes to the current environmental changes. The central approach of our study is to investigate the ability of the hermatypic corals *Porites furcata* and *Agaricia tenuifolia* to vary between autotrophy and heterotrophy (trophic plasticity) in order to optimize energy acquirements; a mechanism to increase coral resilience and stress resistance. The corals nutritional status and the symbiotic interactions indicated by the lipid content, zooxanthellae density and chlorophyll a are used to investigate the corals adaptation pattern at differently impacted sites along the bay. Feeding experiments, applying 13C, 15N isotope phyto- and zooplankton labeling techniques, are used to follow metabolic pathways and exchange processes between the host and the zooxanthellae symbiont. The *de facto* metabolic use of these different food sources is assessed to investigate decoupling mechanisms and the ability of corals to use different kinds of food sources to acquire energy. Results indicate that the investigated coral species become widely abundant due to their heterotrophic competence, which helps them maintain their lipid reserves and to survive symbiotic dysfunctions from bleaching. Knowledge about corals adaptive filter capacities (through heterotrophy) provides quantitative information, and thus important clues for management, helping to develop guidelines for protected area networks.

19A Human impacts on coral reefs
Tuesday 10 July, 1545, Sebel Kuranda

Ningaloo Reef, WA: how do we manage our natural environments?

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The Ningaloo Reef and Exmouth Gulf region is of significant cultural, conservation and economic importance and, an increase in tourist activities, urban and offshore industrial development requires a multi-sector approach to managing this region. An ecosystem agent-based approach (InVitro) was used to model these activities, developments and the major biophysical and ecological processes that occur within this region. A wide range of resolutions were used, from entire habitat types down to the individual behaviour of some agent types (e.g. animals, farmers and/or tourists), which allowed a closer investigation of the level of interaction between all parts of the ecosystem. The model was employed to assess the likely outcomes and trade-offs involved in different potential future developments and management actions within this valuable region. Model outcomes will be provided at a wide range of spatio-temporal scales and key uncertainties highlighted.

19A Human impacts on coral reefs
Tuesday 10 July, 1200, Sebel Kuranda

2011 Fukushima nuclear accident: implications for the tropical Asia/Pacific region

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International Commission on Radiological Protection recommendations seek to prevent or reduce deleterious radiation effects ensuring negligible impacts on biological diversity, species conservation, or ecosystem health. However, existing science on radiation effects on marine biota is limited and uses conceptual or numeric models and reference animals and plants that are representative of temperate regions. For tropical or coral reef ecosystems there are insufficient data available for effective

radio-ecological risk analysis. Recent experiments were undertaken to determine the uptake rate and biological half-life of several radionuclides in corals (*Acropora formosa* & *Goniopora fruticosa*). These data establish seawater-organism transfer factors and internal dose rates essential for radiological impact modelling. There is a need for supplementary studies on mortality or morbidity, fertility or fecundity and chromosomal damage - largely due to radiation (gamma/photon, neutron) generated free-radical (ROS) species. An ecological approach, to gain a better understanding of the relationships between dose and effects at different life cycle stages of different populations, is also needed. Responding to the 2011 Fukushima Daiichi nuclear power plant accident and the rapid expansion of nuclear power facilities in Asia, the International Atomic Energy Agency has established a project titled Marine benchmark study on the possible impact of the Fukushima radioactive releases in the Asia-Pacific Region (2011-15) to address regional gaps in knowledge and capabilities for monitoring, assessment/risk analysis and response. The project involves 24 Asia/Pacific countries. Despite shortcomings, a marine radio-ecological risk analysis of the Fukushima accident has been prepared and will be discussed with reference to data, and knowledge, limitations and gaps and recommendations for the Asia-Pacific region.

19A Human impacts on coral reefs
Tuesday 10 July, 1530, Sebel Kuranda

Dynamics of reef-based livelihoods in Punta Cana, Dominican Republic

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Over five decades, tourism-led coastal development has reshaped access and use patterns on the coral reefs of Punta Cana. We examined these changes to understand the behavior of user groups. The synergy and conflicts among them influence the nature and extent to which conservation measures can maintain coral reef health. Using ethnographic surveys and life-history narratives, we found that privatization and development of coastal resorts triggered mass domestic migration with fishing as an interim sustenance activity in between tourism-based jobs. Displaced fishing villages to locations inland have resulted in novel capital owner-crew relations to meet the resulting transport needs from inland settlements to fishing grounds. Beach access and entry to near shore fishing grounds have become restricted with the construction of on-shore facilities. The fight for fishers' interests including alternative livelihoods and resource conservation provides fishers impetus to organize into fishing associations. For resort companies in the area, the inability of central government to enforce environmental standards gives them free reign. They may choose to be green or pursue mass tourism. The pioneering vision of Grupo Punta Cana (GPC) for low-density growth may be threatened by massive high-density construction around its property. Fishery-independent data indicate overfishing with declining fish density, size and biomass; and decreasing live coral cover, from 2003 to 2007. The near shore waters are phosphorus-enriched. Still, reef yield is at 3.4 tons km^{-2} yr^{-1}, providing full-time self-employment and seafood for local consumption. Structural change and wider support from businesses are needed to halt reef decline.

19A Human impacts on coral reefs
Tuesday 10 July, 1700, Sebel Kuranda

Assessing community resilience to climate change

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Settlements and communities in the Great Barrier Reef (GBR) are highly vulnerable to climate change and face an uncertain social, economic and environmental future. The concept of community resilience is gaining momentum as stakeholders and institutions seek to better understand the social, economic and governance factors which affect community capacity to adapt in the face of climate change. This paper defines a framework to benchmark community resilience and applies it to a case study in the Wet Tropics in tropical Queensland within the GBR catchment. It finds that rural, indigenous and some urban populations are highly vulnerable and sensitive to climate change, particularly in terms of economic vitality, community knowledge, aspirations and capacity for adaptation. Without early and substantive action, this could result in declining social and economic wellbeing and natural resource health. Capacity to manage the possible shocks associated with the impacts of climate change and extreme climatic events is emerging and needs to be carefully fostered and further developed to achieve broader community resilience outcomes. Better information about what actions, policies and arrangements build community resilience and mobilise adaptive capacity in the face of climate change is needed.

19A Human impacts on coral reefs
Tuesday 10 July, 1715, Sebel Kuranda

Direct dredging and shipping impacts on southeast Florida coral reefs

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Many coastal regions have experienced extensive population growth during the last century. Commonly this growth has led to direct impacts to shallow-water coral reefs to accommodate the transit of human goods by large ocean-going vessels. Port development, expansion, and increased vessel activity can have devastating effects on a coral reef ecosystem. In southeast Florida, three major ports built in the late 1920's and early 1930's reside within 112 km of coastline in close proximity to a shallow coral reef ecosystem. Recent and historical mapping data were analyzed in GIS to quantify the type and amount of coral reef habitats directly impacted by shipping and port activities. A total of over 587 hectares (ha) (5.87 km²) of coral reef habitats have been directly impacted by shipping and port activities. Previous dredging accounted for 84.5ha of reef removal for inlet channels. Burial by dredge material accounted for 175.8ha. Although the full extent of all ship groundings is unknown, the measured extents totalled over 8.9ha. And 317.5ha of coral reef habitats are currently located within a large ship anchorage area which is frequently impacted. Expansion by two of the ports plan to remove approximately 9.95 ha more coral reef habitat by blasting and dredging in the near future. Ongoing marine spatial planning efforts are evaluating the large ship anchorages to greatly reduce future impacts by ship anchoring. However, increasing populations and shipping needs will likely continue to be prioritized over protection of these valuable natural resources.

19A Human impacts on coral reefs
Tuesday 10 July, 1230, Sebel Kuranda

Ordnance reef coral impact assessment and mitigation

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The underwater environment presents significant challenges for recovery of military munitions. The Department of Defense (DoD) is responsible for addressing the legacy of contamination associated with these munitions, including unexploded ordnance (UXO) present from current and former testing and training ranges and disposal of discarded military munitions (DMM). Current remedial practices often employ divers for manual retrieval of munitions which presents significant explosive safety risks. Alternatively, blow-in-place detonation of munitions is also often employed which can result in significant injury to corals and other natural resources present in the area. In an effort to evaluate the use of remote means to recover munitions, the U.S. Army completed a demonstration of the Remotely Operated Underwater Munitions Recovery System (ROUMRS) in July 2012 to recover DMM present off the coast of Wai'anae, Oahu, Hawaii. Working in collaboration with the DoD, the National Oceanic and Atmospheric Administration (NOAA) and the State of Hawaii we surveyed corals and munitions present in the area prior to initiation of the recovery effort. This allowed for the demonstration project to be planned and executed in a manner that minimized injury to corals present. Post-recovery surveys documented injury to corals that did occur and will allow for the design of a coral mitigation project appropriate for the injury that was identified. Details regarding the pre- and post-recovery surveys and coral assessment and mitigation process will be presented.

19A Human impacts on coral reefs
Tuesday 10 July, 1145, Sebel Kuranda

Effects of introduced predatory Grouper Roi on Hawaiian fish assemblage

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Prior research findings on the impact of introduced roi (*Cephalopholis argus*) showing a potential consumption of 8.2 million fish year^{-1} (93.7 metric tons) from the reefs of west Hawai`i have focused the attention of fishermen on this species as a management concern. Controversy exists between fishers and managers who observe that prey populations are not driven by roi abundance in west Hawai`i. Beginning in spring 2011, we implemented a Before-After-Control-Impact strategy to detect changes in native fish community structure in the absence of roi. We established 48 belt survey transects in control and removal areas to obtain baseline fish size and abundance data. Researchers and local spear fishermen then removed 25 roi from three acres of patch reef and completed two additional survey rounds following this initial removal. Preliminary analysis shows a significant decrease in roi abundance subsequent to removal ($p=0.045$, $df=2$, $F=3.37$). Changes in fish community structure

are expected to occur on the scale of 1-5 years. Subsequent efforts removed an additional 2 roi from the removal zone. In conjunction with this experiment, divers tagged 67 roi adjacent to the experimental removal reef. Tow boarding surveyors recorded roi size and abundance over 100 acres of similar habitat including control and removal areas, and five tagged roi have been resighted to date. The experiment is ongoing and results will be used to inform roi management by quantifying impact and determining feasibility in response to fishing community concern.

19A Human impacts on coral reefs
Tuesday 10 July, 1245, Sebel Kuranda

Assessment of the lionfish invasion off Bocas Del Toro Archipelago

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This study is part of an ongoing monitoring program focussing on the recent lionfish invasion off Bocas Del Toro Archipelago, Caribbean coast of Panama. Data on lionfish population density were recorded within an area of 1250m², using the visual census methodology on the reef of Punta Caracol, in Bocas Del Drago and compared with local reports. This province of Bocas de Toro still refuges a low density of lionfish, which for the most part were less abundant than their native competitors, the groupers (0.032 and 0.184 fish/m², respectively). Ten lionfish specimens were collected in order to conduct stomach contents analysis which revealed a carnivorous diet of small fish and shrimps. The largest individual collected herein was 23 cm in length which, was not the maximum recorded for Bocas, as in previous "Spear Lionfish" roundups, over 500 lionfish were collected in few hours, with the biggest one being 29.5 cm. Unfortunately, the lionfish population is rapidly expanding as local reports describe. As juvenile fish and shrimp are the major food source for native fish, the lionfish population expansion could cause cascading trophic impacts on economically important species of Bocas del Toro and result in niche takeover by lionfish. Harvesting initiatives by divers are expected to be an effective control strategy especially for locations with high numbers of lionfish and of high ecological importance.

19A Human impacts on coral reefs
Tuesday 10 July, 1215, Sebel Kuranda

19B Coral reef resilience, conservation & management

Environmental and ecological drivers explain variation in bleaching across Indonesia

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During the 2010 mass coral bleaching event, reefs across Indonesia experienced bleaching although the severity of bleaching varied among parts of the archipelago. We assessed bleaching severity (colonies affected and mortality) at 39 sites on coral reefs in three areas - Aceh, Bali and Wakatobi - during and up to 9 months after peak temperatures. We also assessed differences in thermal stress during bleaching and past variability in summer temperatures (thermal history) in each area from satellite imagery. Although coral bleaching was always associated with elevated sea surface temperature, spatial variability in thermal stress during the bleaching event did not explain differences in bleaching severity. Bleaching was most severe in Aceh (>40% mortality) which experienced less thermal stress than Bali and Wakatobi (<5% mortality). In Aceh, historical variability in summer temperatures is low relative to other sites. This suggests that thermal history can be an effective predictor of spatial patterns in bleaching impacts, as has been shown in east Africa and parts of the Pacific. Within each study area, differences in bleaching severity among sites were not well explained by variation in resilience scores based on the IUCN (2009) methodology but were partly driven by the proportion of the community made up by bleaching-susceptible taxa. This suggests that incorporating assessments of thermal history and community composition into resilience assessments can improve

identification of areas likely to be most tolerant to future bleaching events. This information can be used to improve the design of resilient MPAs and MPA networks.

19B Coral reef resilience, conservation & management
Monday 9 July, 1030, Sebel Kuranda

Cayman Islands Marine Protected Areas, a 25 year legacy

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Marine Protected Areas may present a viable solution for the survival of coral reef communities, providing refugia from overfishing and habitat degradation, increasing resilience against stressors from invasive species and climate change. MPAs are predicted to benefit adjacent areas by larval export and net migration. In this study, 62 sites around three Cayman Islands were surveyed for parameters of reef health (fish communities reported elsewhere). Sites within no-take areas, having 25 years of protection, were compared to unprotected sites. Coral cover on Grand Cayman and Little Cayman was higher within MPAs (P=<0.05) and macroalgae lower (P<0.001). Coral recruitment was higher for all islands within MPAs (P=<0.05). A total of 10 diseases were recorded across the Cayman Islands, and although disease prevalence was low (9.11% ±0.79 S.E.), they occurred at most sites (93%), with no significant difference between protected and non protected areas. Disease prevalence varied between islands (P=0.005) with the greatest prevalence at Cayman Brac (13.11% ±1.19 S.E.) and Little Cayman (10.91% ±1.53 S.E.), and lowest at Grand Cayman (5.79% ±0.97S.E.). Bleaching prevalence was low in 2011 (3.97% ±0.56) and did not vary significantly between islands (two-way nested ANOVA, p=0.593), but did differ significantly with depth (two-way nested ANOVA, p=0.001, 2>1), being significantly higher at deep (6.52% ±0.94 S.E.) relative to shallow (1.89% ±0.39 S.E.) sites. There is evidence that MPAs maintain reef resiliency in Cayman; providing a basis for the review and enhancement of the marine protected area system to make it fit for purpose over the next 25 years.

19B Coral reef resilience, conservation & management
Monday 9 July, 1530, Sebel Kuranda

Corals in highly variable environments are more resilient to ocean warming

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A critical challenge for coral reef managers is to identify communities that are potentially resilient and/or resistant to increases in ocean temperature. Experimental studies suggest that coral assemblages that are frequently exposed to large fluctuations in temperature are better able to withstand thermal stress than reefs in more moderate environments. However, there is limited *in situ* evidence that correlates the natural temperature variability of a reef with the coral response to large-scale bleaching events. We investigated the effects of temperature variability on resilience and resistance of coral communities in two distinct environments in the Palauan archipelago: an exposed rim reef with a small diurnal and seasonal temperature range and a shallow lagoonal reef system experiencing larger temperature variability on these timescales. Information contained within skeletal cores from multiple species was used to assess the response to elevated SSTs associated with the 1998 El Nino event, including the presence/absence and intensity of high-density stress bands within the 1998-1999 growth band. The time required for stressed corals to regain pre-1998 growth rates was used to indicate resilience. We found significant differences in the bleaching prevalence, stress levels, and recovery of corals from each reef system. Corals in the highly variable environment exhibited less bleaching and lower post-event stress than those from more thermally stable environments. These results reinforce the hypothesis that reefs exposed to temperature fluctuations may be more resistant and/or resilient to future increases in temperature. The identification and protection of such areas is critically important for coral reef conservation efforts.

19B Coral reef resilience, conservation & management
Monday 9 July, 1515, Sebel Kuranda

Characterizing disturbances and recovery of Red Sea reefs from coral demographics

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During 2009, the Living Oceans Foundation implemented a rapid assessment protocol to characterize the community structure and health of coral reefs in the Farasan Banks, Saudi Arabia. Coral assessments focused on the diversity, size structure, partial mortality, recruitment, and indicators affecting colony survival. The Farasan Banks covers over 4° latitude and contains diverse marine habitats that differ depending on the oceanographic regime, degree of exposure, and topographic features. There are fringing reefs along the mainland, patch, platform and barrier reefs in mid shelf areas, and coral pinnacles and atoll-like tower reefs offshore. Most of the 52 sites examined had high structural complexity, with reef architecture dominated by massive *Porites* colonies. Widespread coral mortality was evident, with 1/3 of the sites exhibiting near total mortality of adult corals, and extensive recent mortality at other sites from *Acanthaster* seastar (COTS) outbreaks. Coral mortality was greater on midshelf and offshore sites, extending across wide depth profiles. Prolific coral growth in shallow water, however, suggests that recent bleaching events were not the primary cause of mortality. Direct human impacts were minimal, with the exception of fishing. Limited turf algal overgrowth, low cover of macroalgae, and high abundances of juvenile corals and recruits on reefs that experienced high adult mortality are indicative of a trajectory of recovery. Nevertheless, COTS outbreaks may be related to overfishing of predatory fishes, and increasing use of fish traps may be compounding pressure on herbivores, with significant ecological implications for future recruitment and survival of juvenile corals.

19B Coral reef resilience, conservation & management
Monday 9 July, 1215, Sebel Kuranda

Globalization explains diversity and function of coral reef fish assemblages

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There is overwhelming evidence that many local scale human activities (e.g.fishing) have a deleterious effect on coral reef fish assemblages. Our understanding of how broad social phenomena (e.g. socioeconomic development) affect the diversity and function of coral reef fish assemblages however, is still poor. Here, we use structural equation models to reveal how human population density, socioeconomic development, and market access affect fishing pressure and coral cover to, in turn, explain the diversity and biomass of key functional groups of reef fish assemblages within Solomon Islands. Fishing pressure is predominantly driven by both market access and local population density, and has a clear negative effect on the diversity and function of coral reef fishes. The strong positive effect of market access on fishing pressure makes clear the importance of understanding human-environment systems in the context of a globalized world. This study highlights the need to address broad social phenomena rather than focusing on proximate threats such as fishing pressure, to ensure the continued flow of coral reef goods and services.

19B Coral reef resilience, conservation & management
Monday 9 July, 1700, Sebel Kuranda

Invasion and succession of corallimorph *Rhodactis howesii* at Palmyra Atoll

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As coral cover declines globally, proper management and conservation of the remaining healthy reefs is becoming increasingly important. However, even remote and near pristine reefs are not free from impacts. On Palmyra atoll, a National Wildlife Refuge and new National Marine Monument, a corallimorph, *Rhodactis howesii*, is causing phase-shifts on previously coral dominated habitat. This phase-shift was first observed after the 1991 wreck of a long-line vessel on the reef, ten years later the corallimorph had spread to cover an area greater than 2km^2. The ecology and mechanism of the corallimorph's invasion is largely unknown. One hypothesis is that iron from the shipwreck added a previously limiting nutrient to the waters creating the ideal conditions for the species to grow. Our research is focused on understanding the causes and consequences of the corallimorph invasion with the goal of helping to inform a well-structured management plan to assist in reef restoration. Specifically, we are using a series of laboratory iron enrichment experiments to determine if growth or physiology of the corallimorph is affected. Additionally we are investigating various methods to control the corallimorph *in situ* and are recording colonization and succession in these removal plots over time. Our results will be important for improving our understanding of this invasive species, *Rhodactis howesii*, and advancing our ability to better manage reefs impacted by this species.

19B Coral reef resilience, conservation & management
Monday 9 July, 1745, Sebel Kuranda

Modeling trilateral partnership in coral reef conservation and anagement, Vanuatu

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The Republic of Vanuatu is an independent island archipelago in the South-West Pacific. The country has over 220,000 people. Rural communities are engaged in subsistence agriculture and small-scale fisheries. One of the most culturally diverse countries in the world, Vanuatu has a rich history of natural resource management. Efate is the central island in the Republic of Vanuatu hosting the nation's capital city, Port Vila. Being the doorway and centre of all developments to Vanuatu this has placed Efate's natural resources at a critical stage for their survival and sustainability. With the ever-increasing impact of population growth and cash economy in Vanuatu, rural communities on Efate are pressurized to sustain their livelihoods with their limited resources. In 2004 two environmental non-governmental organizations (NGO) namely The Foundation for the Peoples of the South Pacific Vanuatu (FSP-V) and Wan Smolbag Theatre (WSB) partnered with the Vanuatu Fisheries Department (VFD) to work with local communities in north Efate to manage their Coastal resources, thus creating this trilateral partnership model of Community-Government-NGO. The community with its traditional resource management knowledge, the government with its national governance capacity and scientific input from the Fisheries department and the introduction of innovative resource management practices by the non-governmental institutions has created this unique and collaborative model of coastal resource management in Vanuatu. Today this trilateral partnership model is working in several coastal communities in Vanuatu where conservation and management actions are implemented to enhance the health of coral reefs to sustain the communities' livelihood options.

19B Coral reef resilience, conservation & management
P210

Changes in onshore-offshore benthic structure with herbivory and nutrients

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The relative importance of bottom-up (nutrients) and top-down (herbivory) factors in controlling the shift of desirable, coral-dominated reef systems into the alternate stable state of undesirable, macroalgal-dominated reef systems is heavily debated in the literature. One major source of conflict is the fact that it is hard to determine which factors are causing a shift when multiple stressors are all occurring at once. Regardless, a trend toward macroalgal increase has been demonstrated on reefs around the world. Reefs that are suffering from a higher number and intensity of stressors are the forerunners of this unfortunate trend. Nearshore reefs are known to be particularly vulnerable due to their close proximity to human activities (e.g, sedimentation) while offshore reefs are somewhat bufferered. This project manipulated two common reef stressors, herbivore intensity and nutrient levels, on nearshore and offshore reefs in the United States Virgin Islands (USVI). We hypothesized that nearshore reefs would respond faster and exhibit a more drastic response to the additional stressors since they are assumed to be at higher background stress levels. Preliminary results reveal that caging had a significant effect on algal growth (AFBM) across time (df=13, p=0.0323) but nutrient addition did not (df=13,p=0.3954). There was no difference in new algal growth between nearshore and offshore treatments over time (df=13, p=0.5104), although macroalgal biomass tended to be higher offshore. This suggests that over the season studied macroalgal growth was not responding to onshore-offshore patterns of stress.

19B Coral reef resilience, conservation & management
P211

Coral-reef ecosystems across Micronesia: patterns, processes, and human footprints

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Across Micronesia, coral-reef ecosystems are inherently linked to social and economic prosperity. However, localized stressors, acting alone or in conjunction with climate-induced disturbances, are key threats to the integrity of coral reefs. Here, an expansive body of evidence is synthesized from many collaborative coral and fish monitoring efforts conducted throughout Micronesia, encompassing datasets from nearly pristine atolls to major population centers. Significant regressions between coral-reef status metrics and proxies to human stressors were consistently found at regional, jurisdictional, and island scales. In all cases, human population, distance to population center, reefsize, and management status were combined predictors of reef condition (defined). More insightful, the slopes of ecological-anthropogenic regression models were flattened where proxies to human influence

were highest, purporting a larger, more evenly distributed extent of influence. From these models, regional status is summarized, and causative insight that helps to define trophic cascades is formulated. Empirical data support that increased fishing pressure (i.e., grazer removal) is a more influential driver of regional coral-reef degradation patterns than land-based pollution. In support, fisheries-dependent datasets across Micronesia found unsustainable harvesting of many target herbivores/detrivores and environmentally constrained catch success derived from commercial market landings; trends that also point to the presence of spatially-extensive gradients. While natural (i.e., atolls) and anthropogenic (i.e., disturbed watersheds) nutrient enrichment are certainly influential drivers of local coral-reef assemblages, it is argued that natural productivity and a limited extent of watershed pollution, in comparison to spatially-extensive fishing pressure, currently exist. Improved fisheries policies are therefore discussed.

19B Coral reef resilience, conservation & management
Monday 9 July, 1200, Sebel Kuranda

Ignoring soft sediment may compromise coral reef ecosystem function

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Marine soft sediment covers 80% of the ocean floor, and is associated with a wide variety of ecosystem functions including providing habitat, refuge and movement corridors for biological organisms, a base for food web structure and dynamics, biogeochemical recycling of nutrients, detoxification of pollutants, and dissipation of oceanic forces. In the US Pacific Islands, there is an unspoken assumption that this habitat type has little to no functional value. This allows continuous largely un-managed anthropogenic impacts to soft sediment to occur, which is concerning as this habitat type plays a role in overall coral reef ecosystem function. It is sensible to focus greater effort on scientifically evaluating how impacts to soft sediment function relate to coral reef ecosystem function, and to take steps to manage this habitat type. A first step is to regulate permitted actions that may impact this habitat type via the implementation of relevant US natural resource mandates. The Magnuson-Stevens Fishery Conservation Act (section 305(b)(1)(A)) for example, provides NOAA Fisheries legal authority to regulate impacts to all benthos, including soft sediment, from shoreline down to 100m depth as it is Coral Reef Ecosystem Essential Fish Habitat (50 CFR 600.905-930).

19B Coral reef resilience, conservation & management
Monday 9 July, 1500, Sebel Kuranda

Coral reef condition on community based-MPA in Eastern Indonesia

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A three year study was carried out in 67 Marine Protected Areas (MPA) at Buton District, Southeast Sulawesi. The research was focused on establishing coral reef condition within the MPAs three years after their establishment. All MPA's were created through community participation. The Point Intercept Transect (PIT) Method was used to determine the coral reef condition at 67 stations within the Buton District MPAs. In 2007, the coral reef composition averaged 30.1% live coral, 40.0% dead coral, 17.2% other fauna, and 10.5% of abiotic substrate (sands and stones). In 2008, coral reef cover consisted of 30.5% live coral, 38.0% dead coral, 9.6% other fauna, and 21.9% abiotic substrate (sands and stones). In 2009 average coral cover changed to 31.6% live coral, 26.0%, dead coral, 13.2% other animals and 20.2% abiotic substrate (sand and stones). From this data we can see a slight increase in live coral reef cover between 2007-2009. We can also see a decrease in dead coral cover three years after the establishment of community based MPAs. Community based MPAs provide the best protection for coral reef species including fish and other wildlife. This approach has maximised the capacity of the local community who can often serve as the best managers and supervisor to ensure the protection of these areas from overfishing, bombing and cyanides. This is one of the most successful strategies on marine conservation in Indonesia.

19B Coral reef resilience, conservation & management
Monday 9 July, 1645, Sebel Kuranda

Condition and management of coral reefs in Veracruz, Mexico

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The National Park Sistema Arrecifal Veracruzano in Veracruz, Mexico

encompasses 52,238 hectares, contains 23 coral reefs, is a Ramsar site and a Biosphere Reserve. However, a management plan for the use and protection of the Park's coral reefs has not been created. Thus, an effort to evaluate the current reef condition has been initiated with the aim of providing managers with the necessary information to generating guidelines for such a plan. From 2007 to 2011, benthic coverage of stony corals, algae, sponges and gorgonians, and has been estimated from 563 point intercept transects at 66 sites on 22 reefs. Additionally, stony coral colony size has been measured and presence/absence of stony coral disease recorded at each transect. Results showed that coral cover ranges from less than 1 percent to over 40 percent. Based on coral cover, the Park can be subdivided into 2 groups: a northern group near the port city of Veracruz (coral cover site average of 15%) and a southern group close to the fishing town of Anton Lizardo (24%). Coral colonies were up to 400cm in size. Several areas with moderate to high densities of *Acropora cervicornis* and *A. palmata* were identified. Percent coral cover and colony sizes exceed that of many Caribbean reefs. The presence of threatened Acroporid corals is also exceptional considering the pressures these reefs face. The coral reefs of Veracruz are unique and we present a plan to protect them from the effects of urban and commercial development.

19B Coral reef resilience, conservation & management
Monday 9 July, 1730, Sebel Kuranda

Managing reef fisheries for sustainable ecosystem function

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Much is written about taking an ecosystem-based approach to fisheries but there are few practical examples of good practice. Biogenic habitats, such as coral reefs, provide an excellent opportunity to develop such ecosystem-based approaches because the fishery - in this case, for parrotfish - affects the reef health through grazer-mediated ecological cascades. Here we create the world's first 'coral friendly' fisheries policy that attempts to set 'safe limits' for parrotfish exploitation while facilitating sustained reef resilience and function. We present a model of parrotfish population dynamics and couple this to an ecosystem model of a Caribbean reef that includes both ecological and geological processes. We identify levels of parrotfish catch that allow net accretion of Caribbean reefs for the next 50 years. Our approach will help managers set explicit targets for fisheries that attempt to consider the impact of the fishery on the wider coral reef ecosystem.

19B Coral reef resilience, conservation & management
Monday 9 July, 1000, Sebel Kuranda

Consideration of disturbance history in design of resilient MPA networks

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Coral reef resilience to mass bleaching from sea surface temperature anomalies is partly determined by the frequency and severity of recent disturbance. When prioritizing sites for management in a previously unstudied area, managers need to consider how these temporal dynamics impact present coral conditions indicated by field survey data. In March-April of 2010 and 2011, we surveyed 179 coral reef sites across five districts of southwestern Vanua Levu, Fiji, with the aim of collecting information to inform the design of resilient marine protected areas (MPAs). Most reef sites in the northeastern district were severely impacted by a tropical cyclone in 2010 and a crown-of-thorns outbreak in 2011, while some inshore fringing reefs were chronically disturbed by episodic river runoff. At each site, we measured a suite of factors predicted to confer resistance to bleaching and potential for recovery, including coral taxa dominance, benthic cover composition, and colony stress, indicated by damage from bleaching, bioerosion or predation. We used a multidimensional ordination to cluster sites based on site susceptibility to bleaching (calculated by taxa dominance weighted by thermal tolerance), proportional cover of hard corals plus crustose coralline algae (CCA), and proportion of stressed colonies and thus identify priorities for management. Priority sites for inclusion within the MPA network included: (1) undisturbed sites with high coral-CCA cover, dominated by large reef building taxa with higher thermal tolerance (e.g. *Porites, Pavona*); and (2) disturbed sites with intact reef structure and moderate cover of bleaching-tolerant species, coupled with high herbivore biomass and juvenile coral density.

19B Coral reef resilience, conservation & management
P212

Long term, *in-situ* recovery of *Montastrea franksii* following bleaching

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The survival and recovery dynamics of individual corals following a significant disturbance event such as widespread bleaching may provide an indication of the future of the reef as a whole. As disturbances increase in both number and extent, as predicted given forecasts of future temperature increases, the recovery or mortality dynamics of individual colonies will underlie the long-term response of populations and the overall health of existing ecosystems. The seven-year photographic time series presented here begun immediately following the major 2005 bleaching event, with *Montastrea franksii* colonies in Almirante Bay, Bocas del Toro, Panama monitored annually for growth or recession, along with symbiont type changes monitored through 18S ribosomal subunit DNA analysis. In the most recent year these same colonies were monitored more extensively with Pulse Amplitude Modulated fluorometry, multi-spectral fluorescence photography, an analysis of pigment composition, and measurements of live surface area, to determine residual physiological impacts on the colonies. These colonies have shown a wide individual variety of growth responses to the initial environmental disturbance, and the factors driving this individual difference in recovery, such as symbiont diversity, as investigated in this study, may hold clues to both the individual and long-term persistence of this species in this area.

19B Coral reef resilience, conservation & management
Monday 9 July, 1715, Sebel Kuranda

Mapping spatial resilience of Hawaiian coral reefs

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The theoretical development of coral reef resilience has been substantive over the past decade. Advancements of how to operationalize resilience theory have however lagged behind, and concerns regarding its practical applicability have been raised. Operationalizing coral resilience, and making it 'measurable' and 'observable', remains a challenge for researchers. One potential pathway to operationalizing the concept is to develop a range of indicators that capture different component(s) of coral reef resilience, such as biodiversity, key processes and connectivity. In this project we aim to quantify the spatial resilience of individual coral reefs that are monitored throughout the Hawaiian Islands. We will use an aggregate measure (a 'state variable') of resilience, comprised of different indicators of coral reef resilience, such as functional group diversity and evenness, demographic characteristics of key organisms and herbivore grazing capacity. The practical impact will be the development of spatially explicit maps of Hawaiian reef resilience across the archipelago.

19B Coral reef resilience, conservation & management
Monday 9 July, 1130, Sebel Kuranda

Fishing-induced trophic cascades reduce coralline algae cover and subsequently reduce coral recruitment

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Removal of predatory fishes has effects that cascade through ecosystems via interactions among species and functional groups. In Kenyan reef lagoons, fishing-induced trophic cascades produce sea urchin-dominated grazing communities that greatly reduce the overall cover of crustose coralline algae (CCA). Certain species of CCA enhance coral recruitment by chemically inducing coral settlement. If sea urchin grazing reduces settlement-inducing CCA cover, coral recruitment may also decline on fished reefs. To determine whether fishing influences coral recruitment through changes in CCA, we compared 1) CCA taxonomic compositions, and 2) taxon-specific associations between CCA and coral recruits under three fisheries management systems: closed, gear-restricted, and open-access. On fished reefs (gear restricted and open access), abundances of two species of settlement-inducing CCA, *Hydrolithon reinboldii* and *H. onkodes*, were half those on closed reefs. Recruitment by four common coral families (*Poritidae*, *Pocilloporidae*, *Agaricidae*, and *Favidae*) was higher on *Hydrolithon* than on any other settlement substrate on both closed and fished reefs. Coral recruit densities were positively correlated with *Hydrolithon spp.* cover, and were significantly lower on fished than on closed reefs, suggesting that fishing indirectly reduces coral recruitment over large spatial scales via reduction of settlement-inducing CCA. Therefore, managing reefs for higher cover of settlement-inducing CCA may enhance coral recruitment and help to maintain the ecological and structural stability of reefs.

19B Coral reef resilience, conservation & management
Monday 9 July, 1145, Sebel Kuranda

Patterns of hurricane-induced *Acropora* mortality in the Florida Keys

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Climate change scenarios predict stronger and more frequent hurricanes. We studied survival patterns of *Acropora palmata* during the hyper-active 2005 Atlantic Hurricane Season to assess future effects of routinely elevated storm seasons. Before the start of the 2005 Atlantic Hurricane Season, 105 colonies on three survey reefs in the EPA/NOAA Coral Reef Monitoring Project were marked and tracked through 2007. Only 13 of the original 105 marked colonies survived the 2005 AHS (12%). When grouped into classes based on a combination of size, morphology, and position, results show a highly significant interaction between these classes and survivorship (Chi Sq. = 23.61; d.f. = 1; $p < 0.0001$). None of the large, 3-D exposed corals, and few of the medium, 3-D exposed corals survived. By contrast, highest survivorship occurred among small, 2-D protected corals. Medium-sized, 2-D protected corals had intermediate survival rates. None of the corals that were loose on the bottom survived. By asexual reproduction mechanisms such as breakage and fission, the so-called 'Sorcerer's Apprentice Effects', these 13 original colonies were represented on the post-hurricane reef by 33 distinct propagules (9 pieces by breakage and 24 by fission). None of the colonies formed by breakage and only 3 of the colonies formed by fission remained by 2007. No putative sexual recruitment was observed in the two years following the 2005 AHS. As a matter of public policy, we should undertake colony cementation and snail removal as perhaps the only way to promote *Acropora palmata* regrowth and recolonization following catastrophic disturbances.

19B Coral reef resilience, conservation & management
Monday 9 July, 1630, Sebel Kuranda

Establishing a network of marine managed areas using resilience surveys

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Although calls for networks of representative marine protected areas have been frequent and global in the past two decades, progress towards on-the-ground protection in developing countries has faltered severely due to lack of financial resources, technical capacity, institutional will, and stakeholder opposition. Establishing networks of marine managed areas (MMAs), that may or may not include protected no-take zones, provides more opportunities for legal designation, credible establishment, effective and comprehensive management of marine resources than strict MPAs or individual, un-linked MMAs. We utilize this approach in the Maldives where coral bleaching and mortality following the 1998 El Nino event was severe, and where more than 100 individual island resorts provide the most credible platform for coral reef management in the country. Ecological surveys to assess reef resilience on individual islands were used to develop in house reef management plans, endorsed by government and resort managers. Key strengths of this approach include the capacity to address local and regional scale ecological patterns and management needs. Small Island Developing States with large geographical expanses and many reefs such as the Maldives, this methodology may present a useful approach for managing coral reefs.

19B Coral reef resilience, conservation & management
Monday 9 July, 1545, Sebel Kuranda

Coral reefs in Ambon Bay (Indonesia) need sustainable management

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Ambon Bay is a part of Ambon Island located in eastern Indonesia region. The whole area of this bay is about 124.5 km^2 consisting of a shallow inner bay and a deep outer bay. These two parts of Ambon Bay are linked by a narrow channel, approximately 0.8 km long and 0.6 km wide. In Ambon Inner Bay (AIB), the deepest water is around 42 m, while in Ambon Outer Bay (AOB), it is at least 600 m, and the depth of the channel varies between 9-13 m. Coral reefs are mainly distributed in AOB. We found 85 species in AOB, and 43 species in AIB. *Flaviidae*, *Poriitidae* and *Acroporidae* are categorized as dominant coral families in Ambon Bay. In general, the condition of coral

reef in AOB was healthier than in AIB. In addition, 122 coral reef fish species, categorized into 35 families, were recorded in Ambon using the visual census technique. *Cromis* and *Dascylllus* are important ornamental fishes which were found in large numbers. Nowadays, the coral reef condition, based on the percent of hard coral cover has declined compared the results of observations in previous years. This is due to the high sedimentation rates into Ambon Bay a result of population growth and continuous land clearing over the past 2-3 decades. Therefore, there is a need for the sustainable management of coral reefs in Ambon Bay.

19B Coral reef resilience, conservation & management
P213

Making it easier to use resilience scores in reef management

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Managing reefs for resilience to climate change is critical as the frequency and severity of climate-related disturbances, like bleaching events, is predicted to increase. Resilience assessment protocols were developed by IUCN and involve measuring or estimating ~61 factors thought to confer resilience to coral reefs, producing a single resilience score. However, little guidance is available on how to interpret and use resilience scores to inform management decisions. In 2009 resilience assessments were undertaken at 123 sites across four locations in Indonesia (Aceh, Karimunjawa, Bali and Kofiau). We developed a framework to improve the interpretation of resilience scores and their usefulness to inform management decisions. After excluding 17 factors we judged were only indirectly related to resilience, we categorized the remaining factors as relating to 'bleaching resistance', 'recovery', or 'anthropogenic stress' which were then combined to produce an overall 'resilience' score. Within each location, sites were ranked as high, medium or low for each category based on the range of scores for that location. A presentation format was developed that facilitates interpretation, making it easier to identify potential management actions that would increase resilience. These may include identification of high resilience sites for inclusion in marine protected area planning, identifying key anthropogenic stressors that are reducing resilience, or identifying actions that would improve resilience across the greatest number of sites. These improvements in the application and utility of resilience assessments aim to facilitate increased incorporation of resilience principles in the management of coral reefs.

19B Coral reef resilience, conservation & management
Monday 9 July, 1015, Sebel Kuranda

Mapping coral bleaching resistance: lessons from the Great Barrier Reef, Australia

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There is a growing demand among managers, policy makers and stakeholders for spatially-explicit information on the risk of coral reefs to climate-related bleaching impacts at a local scale. The value in such information lies in its potential to: (i) identify reef locations that exhibit greater (or lower) resistance to thermal bleaching, (ii) explain the interacting determinants responsible for such reef-scale variability, and where possible (iii) draw attention to local adaptation actions that may help to mitigate the risk. In this presentation, I outline a spatial risk assessment approach for the Great Barrier Reef (GBR, Australia) that helped provide insight with respect to each of these information queries. Notably, the approach provides support for the importance of local water quality, specifically nutrient enrichment, as a contributing determinant of bleaching sensitivity on the GBR. I outline the considerable benefit of this information for: (i) explaining historical bleaching patterns, (ii) testing the bleaching-resistant quality of the current GBR marine protected area (MPA) network, (iii) understanding regional biodiversity patterns, specifically the distribution of host species that harbor symbionts that are known for their increased heat tolerance (clade D), and (iv) targeting regional-specific water quality improvement strategies that promote bleaching resistance.

19B Coral reef resilience, conservation & management
Monday 9 July, 1115, Sebel Kuranda

19C Trade in coral reef wildlife

Coral reef wildlife trade: global goods and shared management responsibility

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Trafficking (i.e. illegal trade) in wildlife has now become the third largest source of money for criminal organizations in the world, following drugs and arms. Presently, most trafficking by these groups is focused on terrestrial species. However, many countries with coral reefs lack the policy and regulatory tools necessary to prevent large-scale trafficking and effectively manage growing trade demands in a way that promotes sustainable use. The international trade in coral reef wildlife is widespread, growing and often involves illegal, unreported and unregulated (IUU) fishing. Unsustainable trade undermines local management efforts and adds to the cumulative stresses that coral reefs are facing from climate change, ocean acidification, overfishing, destructive fishing and land based pollution. Biodiversity is recognized to be both a local and global good, yet international mechanisms designed to ensure sustainable use of these assets are not adequately addressing the coral reef wildlife trade and safeguarding reef benefits for local communities. Source countries and importing countries, therefore, need to share management responsibilities for the coral reef wildlife trade. But how is this done? Examples and recommendations of complementary and precautionary trade policies and regulatory frameworks for exporting and importing countries will be presented. Appropriate policies by importing countries can support efforts by exporting countries to regulate the trade, promote best practices, support local management efforts and create incentives for sustainable use and conservation of coral reef ecosystems.

19C Trade in coral reef wildlife
Wednesday 11 July, 1500, Sebel Kuranda

Stock assessment and ecosystem management of ornamental coral reef fisheries

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Coral reefs support fisheries for ornamental species that are displayed in aquaria around the world. The volume of trade in coral reef derived ornamental species appears to be quite large, implying that impacts on the sustainability of ornamental stocks and on the ecological health of coral reefs may also be large. To date, these impacts have been difficult to quantify. It has been even more difficult to estimate sustainable yield levels that would hedge against overfishing. Here we describe the limitations of conventional approaches to fisheries stock assessment in the context of coral reef ornamental species, evaluate the utility of newer data poor approaches, and propose a framework for assessment and management. This proposed framework rests on new empirical evidence that discrete levels of total fishable biomass - a relatively easy metric to evaluate - correspond to thresholds in coral reef ecosystem state. These discrete thresholds can serve as early warning indicators of ecosystem decline and collapse, and as benchmarks or reference points for whole system management rather than for single species management.

19C Trade in coral reef wildlife
Wednesday 11 July, 1400, Sebel Kuranda

Managing the coral reef wildlife trade: successes, shortcomings, and challenges

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The trade of ornamental coral reef wildlife supports a multi-million dollar industry but also threatens the health of vulnerable coral reef species and ecosystems due to unsustainable practices and a lack of effective regulation. To supply this trade, fishermen often overexploit fish populations and use fishing practices, such cyanide fishing, that harm coral reef organisms and habitats. Despite its negative impacts, the trade is growing and now involves at least 45 countries and an enormous diversity of species: over 2020 fishes, 500 invertebrates, and 200 corals. The scale and scope of the trade present a challenge to sustainable management. Yet, a number of laws, management strategies, and trade reforms have already been implemented worldwide with varying efficacy. We first review the range of management practices that have been implemented in diverse settings (e.g. developing and developed countries, source and buyer countries) and lessons learned about barriers to effective management. We then highlight key differences between the life histories of fishes caught for the ornamental trade (e.g., yellow tang) and for food (e.g., tuna) and discuss the management implications of these differences. In general, ornamental fisheries are characterized by high levels of illegal, underreported, and unregulated fishing and by limited data on population dynamics, stock status, and

collection effort. Also, ornamental fisheries target juveniles, so applying traditional fisheries management tools (e.g. minimum size limits) is more difficult. In order to design effective management, we must understand previous management attempts and how differences in the biology of ornamental species change optimal management strategies.

19C Trade in coral reef wildlife
Wednesday 11 July, 1445, Sebel Kuranda

Illegal marine wildlife trade field investigation training

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The International Coral Reef CSI (CRCSI) Program provides practical field training for coral reef resource managers and enforcement officers, focusing on underwater techniques for collection of evidence and formal documentation of human-induced natural resource injury events. Recently the Program was encouraged to focus more on in-water enforcement issues, early detection of impact or injury, and strategies for dealing with trans-border illegal trade issues associated with aquatic life. While efforts to investigate illegal trade at the site of origin (versus interdiction while in transit or at the receiving end) hold stronger likelihood of enhancing compliance relative to natural resource impacts and broader ecosystem secondary impacts, few standard operating procedures, training courses or tools are available to assist most coral reef countries, their management agencies or their field personnel in this direction. The CRCSI Field Training workshops have been very successful in this effort, involving investigation of injured aquatic life or habitat. We are now using the same successful techniques for the issues outlined above by developing add-on training modules that can be incorporated into both the CRCSI Toolkit and for incorporation into the training workshops. This talk will describe the program, how it functions, and how the training can be used to combat illegal trade in coral reef organisms.

19C Trade in coral reef wildlife
Wednesday 11 July, 1530, Sebel Kuranda

Implications of monotypic data systems for coral reef trade monitoring

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Compulsory data are maintained via government mandates for species listed by the Convention on the International Trade in Endangered Species (CITES) whose records, are often inaccurate or incomplete; listed species comprise a small proportion of the total ornamental aquatic animal trade, (namely stony corals, giant clams, and seahorses). A few studies have attempted to quantify the movement of non-CITES-listed aquarium species from source to market. For the U.S., the Fish and Wildlife Services (US FWS) is charged with inspection of wildlife shipments and maintains species-specific data of such shipments per CITES requirements in the Law Enforcement Information Management Services (LEIMS). Non-CITES-listed fish/invertebrate species, however, are only listed with general codes. Trade data do not contain information on volume, diversity of species, and trade pathways. This raises two questions: first, how can importing and exporting governments monitor this industry effectively; and second, how should sustainability be encouraged given the paucity of data? As coastal managers scrutinize practices of the live animal trade - including efforts to reduce risks from introduction and diseases - the need for accurate accounts of trade data increases while the current monitoring methods are static and prevent detailed analysis of data. Here we present a method for real-time monitoring of the wildlife trade, which can be employed quickly and effectively by both developed and developing nations. We give a unique overview of two years of import data on the volume and biodiversity of marine aquarium fishes.

19C Trade in coral reef wildlife
Wednesday 11 July, 1515, Sebel Kuranda

Management, assessment and monitoring of the Queensland Coral Fishery

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The Queensland Coral Fishery is a low volume, high value fishery operating primarily within the Great Barrier Reef Marine Park. Participation is limited to 59 licences, which are operated by 24 businesses, 16 of whom are also endorsed to operate in the related Marine Aquarium Fish Fishery. The annual combined GVP of these fisheries has been estimated at $10-$12 million. This hand collection fishery has an annual Total Allowable Catch of 200t of which 60t may be collected as living coral and 140t may be collected as dead coral (mostly liverock). A system of Individual Transferable Quota applies with the harvest tracked though a quota monitoring system. Management arrangements are defined in the Fisheries Regulation 2008 and Policy for the Management of the Coral Fishery 2009. The primary assessment tool for the fishery is an Ecological Risk Assessment (ERA) based upon the AS/NZ Standard. Coral taxa from over 36 families are collected. The ERA identified 12 coral taxa and two live rock collection areas that were at low risk from the fishery. In addition, the aquarium supply industry has implemented a Stewardship Action Plan that defines collection standards that specifically address the species identified in the ERA in order to mitigate risk. The outcomes of the ERA are used to focus monitoring of the fishery through a Performance Measurement System (PMS). The PMS measures the fishery's performance against defined ecological, economic and social management objectives with response action required if performance falls outside of defined acceptable ranges.

19C Trade in coral reef wildlife
Wednesday 11 July, 1430, Sebel Kuranda

International trade in hard corals: review of management, sustainability and trends

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Since international trade in hard corals began in the 1950s, there have been major changes in the supply chain, end use and the way coral fisheries are regulated. Traditionally, pieces of dead coral were used either as curios or to decorate aquarium tanks, but international trade in these commodities has declined noticeably in recent years, with many countries prohibiting collection and export. In contrast, since the mid-1980s there has been a steady rise in trade in live corals and live rock (bioactive reef bedrock) for private and public aquaria. Based on import data, trade in coral rock reached a peak of 2,527mt in 2005 but since then has been on a declining trend, falling to 1,233mt in 2010. Trade in live corals is increasing and the main supplier continues to be Indonesia. According to import data, this country has provided an average of 70% of trade in live corals in the past decade. There is now a growing trend towards fragmentation and propagation of corals which are seen as ways of taking pressure off wild populations and as possible solutions for making the trade self-sustaining in the long-term. However, these initiatives have concentrated on the fast-growing, small-polyp corals such as *Acropora* and there has been little or no commercial success with popular large-polyp varieties such as *Catalaphyllia, Plerogyra* and *Trachyphyllia*. This paper provides an analysis of international trade from 2000–2010 and examines the management challenges for sustainable harvesting into the future.

19C Trade in coral reef wildlife
Wednesday 11 July, 1415, Sebel Kuranda

19D Managing fish spawning aggregations

How are your grouper spawning aggregations doing? Ask the fish

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The management of threatened grouper spawning aggregations should be based on a scientific understanding of their status. Traditionally, this is assessed by measuring changes in catch per unit effort and size frequency of the catch. While straight-forward in principal, problems facing managing agencies often make this difficult in practice. These include limited funds and manpower in the face of having to monitor multiple species over several sites, difficulties in working in winter sea conditions and uncertainty over when best to sample. These problems could be overcome by listening for and quantifying the sounds emitted by aggregating groupers using simple recording hydrophones. We have deployed bottom hydrophones to monitor multiple spawning aggregation sites over the course of the spawning seasons for both red hind (*Epinephelus guttatus*) and yellowfin grouper (*Mycteroperca venenosa*). Hydrophones were installed well before the spawning season and recovered after, spreading the effort over time and eliminating the problem of weather dependence. Calibration of both call counts and sound levels against diver surveys indicates that these track density over the course of the season. Results

clearly show when fish spawn, that the day of spawning is variable among sites, and in which months peak aggregations occur. Results can also be used to calibrate diver surveys by standardizing density counts to time of day and time of the lunar cycle. Use of sound levels allows data to be quickly processed, but counting calls may be necessary if multiple species need to be distinguished.

19D Managing fish spawning aggregations
Thursday 12 July, 0945, Plenary Hall 2

Aggregation of *Plectropomus leopardus* at Lankayan Island Malaysia

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The spawning aggregation of coral trout *Plectropomus leopardus* had never been reported in Malaysia. Reported here the first field observation of small aggregation of coral trout reached a maximum of 30 fishes in 1000m^2 at Lankayan Island, Sugud Islands Marine Conservation Area (SIMCA), Malaysia. The aggregation density reached 13-30 fish per 1000m^2 two days before new moon and dropped to 0.5 fish per 1000m^2 after new moon. We observed color variations during aggregation with obvious dark and pale phases. Coral trout showing contrasting color variation are believed to be important for sex-specific communication strategies. Correlations indicated that color variations changed with total length (TL) of coral trout. Observations showed that coral trout with TL of more than 36cm were mostly in the dark phase during aggregation. Aggregation occurred at the reef slope ranging from 12 to 22m. Coral trout with a mixture of dark and pale phases patrolled along the slope exhibited territorial defense behavior. Behavior of open mouth and side waving position observed between dark phase coral trout suggested underwater aggressive symptom. In conclusion, this study further discussed how a decade of protection of SIMCA offered opportunities for recovery of exploited fish stock, to secure spawn-population and aggregation sites which are important for long term sustainability of the species.

19D Managing fish spawning aggregations
Thursday 12 July, 1515, Plenary Hall 2

Spatio-temporal interactions between fisheries and fish spawning aggregations

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Fish spawning aggregations support some of the most productive fisheries worldwide, but most are declining and many have collapsed. Efforts to create sustainable fisheries for aggregating species are hindered by a lack of understanding of the scale at which fisheries interact with spawning aggregations, information that is necessary for management strategy evaluations used to set harvest regulations. We combined GPS data loggers with fisheries and biological surveys to produce fine-scale, spatio-temporal maps of fish movement and fishing activities related to the massive migration of a large and vulnerable marine fish (*Cynoscion othonopterus*) into its only known spawning grounds. We show that spawning and fishing activities are synchronized on a semi-lunar cycle, and 1.3million fish (4,000 t) are harvested over 25 days each year within an area of 656 km^2 of a biosphere reserve. Seventy-five percent of fishing activities occur inside a no-take zone, and peak catch rates occur when corvina are actively spawning. These results indicate that protection of the fishery and enforcement of the reserve may be improved by implementing fishing closures or sales bans during the peak spawning period. Overall, this study demonstrates how identifying the key spatial and temporal scale by which fisheries impact spawning aggregations can help improve the management of aggregations and marine reserves.

19D Managing fish spawning aggregations
Thursday 12 July, 1145, Plenary Hall 2

Reef fish spawning aggregations on the Northeastern Brazilian coast: status of knowlege and management perspectives

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Occurrence of reef spawning aggregations was assessed on the northeastern Brazilian shelf, between parallels 7ºS and 16ºS, as part of a national effort to support management decisions and guide environmental licensing in the region. The shelf is narrow and breaks abruptly at depths of 40 to 80m. Channels and biogenic formations represent traditional fishing

grounds. Aggregations of several species of snappers were reported by fishers. *In situ* verifications were successful for the cubbera snapper in six locations, distant at least 80miles apart. Aggregations occurred from January to April. Evidence included UVC observations, peaks of cpue from landings and gonadal evidences of imminent or recent spawning. Fishers target the aggregations at the new moon, but sightings, including records by recreational divers, were mostly during the full moon. Other species were observed aggregating in the same sites, specifically carangids. The black grouper non-reproductive aggregation known as 'corre' was recorded in 2010. The intensively targeted event was recorded three times in the last 10 years. The local knowledge of artisanal line fishers is site specific, rich and detailed, as fishing during aggregations mean exceptional catches. Abundance declines have been perceived by fishers. Sites are likely to be multispecific and several commercially important species are involved. A lack of management and enforcement, increase of oil and gas prospection, and development of technology powered recreational fisheries figure among the main threats. Co-management through fisheries agreements for seasonal closures and protection of selected sites seems to be the better option under a scenery of mounting pressure.

19D Managing fish spawning aggregations
Thursday 12 July, 1015, Plenary Hall 2

Opportunities and challenges of managing spawning aggregations in Fiji

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Coastal Fijian communities have historically fished spawning aggregation sites for subsistence. As market pressures have escalated, vulnerable aggregations are rapidly being extirpated. There are no provisions within the current Fiji Fisheries Act that provide legal controls on fishing aggregations. However, communities can set customary rules to manage spawning aggregations within local management plans covering their traditional fishing grounds. Their local knowledge can be used to determine the spatial placement of fisheries closures (e.g. across channels and/or on steep fore reefs), as well as the timing of seasonal bans on harvesting spawning species. Although not legally binding, compliance is high when there is strong respect for decision-makers and broad participation in decision-making process. We present an example from Kubulau District, Bua Province, where communities banned grouper catch during the month August but were more reluctant to protect a well-known mullet aggregation site due to the cultural practice of holding an annual feast associated with the congregation of two mullet runs. We further discuss the opportunities as well as limitations to developing nation-wide seasonal bans on aggregating species. For example, the word for grouper in Fijian (kawakawa) includes a number of different species which individually spawn during different months of the years in Fiji, with considerable geographic variation in the timing of spawning. However, these limitations could be addressed through a collaborative campaign between the Fiji Fisheries Department and NGOs to encourage a broad seasonal ban (e.g. July - November) on harvesting the most vulnerable species.

19D Managing fish spawning aggregations
Thursday 12 July, 1115, Plenary Hall 2

Protecting reef fish spawning aggregations in the Coral Triangle

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Environmental non government organisations (NGOs) are increasingly recognising that fish spawning aggregations (FSAs) are a critical component of marine protected area networks. In the Coral Triangle region, The Nature Conservancy has incorporated FSAs into conservation programs through a three phase approach;1) identification of FSAs through local knowledge surveys, 2) independent scientific validation of FSAs and, 3) ensuring validated FSAs receive high priority in large-scale conservation planning processes. Concurrent with these activities have been awareness raising initiatives and the establishment of monitoring programs at FSAs. In the Coral Triangle the most effective FSA management has resulted from community-based initiatives, such as complete fishing bans at the FSA or restrictions on destructive fishing practices. Longterm monitoring of FSAs in New Ireland Province, Papua New Guinea (PNG), demonstrates that even small MPAs can greatly enhance the spawning biomass of aggregating species, and recent connectivity research on the squaretail coralgrouper (*Plectropomus areolatus*) in Manus, PNG, demonstrates that protection of FSAs will greatly enhance spillover of larvae into natal populations. However, our connectivity research also highlights that small-scale management of FSAs will not provide protection from land-based threats, with the majority of *P.areolatus* nursery habitats located on shallow near shore reefs that are highly vulnerable to sedimentation and land-based pollution. Comprehensive protection of species that aggregate to spawn therefore requires an

ecosystem approach to management, and we outline recent efforts to incorporate both FSAs and critical nursery areas into a 'ridges to reefs' planning process currently underway in Manus Province, PNG.

19D Managing fish spawning aggregations
Thursday 12 July, 1200, Plenary Hall 2

Grouper spawning aggregations: understanding their dynamics for effective management

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Fish spawning aggregations (FSA) of groupers are increasingly being overfished throughout the coral triangle. In Solomon Islands, concerns over the declining status of FSAs and a lack of scientific data upon which to base FSA management decisions has prompted a) the development of underwater monthly monitoring projects at two FSAs locations (Roviana Lagoon and Ghizo Is) in the Western Solomon Islands and b) a comparative demographic study on *Plectropomus areolatus* FSAs at the above mentioned locations. Both FSAs support large aggregations of *Epinephelus fuscoguttatus*, *Epinephelus polyphekadion* and *P. areolatus*, and are separated by 70 km. Monitoring data shows *P. areolatus* forms aggregations throughout the year at both sites, with a peak 3-4 month season that corresponds with the much shorter spawning season of *E. fuscoguttatus* and *E. polyphekadion*. This peak spawning period is correlated with elevated sea temperatures. At both locations, the peak spawning seasons for all three species are confined to the first 6 months of the year, although some inter site variability exists. At both sites and for all three species peak FSA densities occur in the 2nd lunar quarter. Demographic studies show significant differences in growth rates and maximum sizes between the two populations. *P. areolatus* at the Ghizo FSA are faster growing and reach smaller overall sizes compared to Roviana. Such differences may reflect differences in the level of historical fishing pressure at the FSAs. Findings imply that FSAs in the Solomon Islands are best protected through marine protected areas and lunar sales/fishing bans.

19D Managing fish spawning aggregations
Thursday 12 July, 1630, Plenary Hall 2

Multi-species grouper spawning aggregation dynamics in Pohnpei, Micronesia

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A multi-species fish spawning aggregation (FSA) was examined over a 12-d period in March 2011 by a 2-person dive team using a combination of Nitrox and closed circuit rebreather. To estimate daily changes in distribution, density, and abundance of three grouper species, sub-surface buoys were placed at 50-mintervals along a 1500-m transect at 30-m depth. Counts were made from ca. 20 m to ca. 80 m that represented the maximum depth of each aggregation. Findings revealed a marginal overlap between adjacent FSA, with observed variability in residency times, abundance, density and distribution among species. Highest abundance and density was observed within the center, or aggregation 'core', where peak abundance over a 50-m section ranged from 400-1100 individuals. Camouflage grouper (*Epinephelus polyphekadion*) and squaretail coralgrouper (*Plectropomus areolatus*) abundances peaked at ca. 3,000 individuals, while more than 1,600 brown-marbled grouper (*Epinephelus fuscoguttatus*) were recorded. Abundance estimates using technical diving were two times the average maximum abundance for brown-marbled grouper and nearly 10 times that for camouflage grouper over a 10-year UVC monitoring period using air-filled SCUBA. For management decision-making, the observed differences highlight the limitations of air, and support the use of technical diving for obtaining accurate estimates of deeply distributed grouper spawning aggregations.

19D Managing fish spawning aggregations
Thursday 12 July, 1545, Plenary Hall 2

A risk based approach to management of spawning closures

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In 2003 new management arrangements, including spawning closures, were introduced for the Queensland coral reef fin fish (CRFF) fishery. Closure timing and duration were based on biological information showing that coral trout form spawning aggregations around the new moon periods between August and December. The spawning closures implemented comprised of three annual 9-day closures around the October, November and December new moons. A review of spawning closures commenced in 2007 with the primary objectives to assess whether existing closures provided adequate protection to key CRFF

species and to ensure that future closures are developed to achieve the same. The main challenge in the review was demonstrating an appropriate balance between ecological, economic and social objectives, in line with the main purpose of the Queensland Fisheries Act 1994. A further challenge was the relatively limited information available to assess the impacts of fishing on CRFF and flow-on benefits to the stock from spawning closures. In addition no direct evidence had been found to demonstrate that commercial reef line fishers were targeting spawning aggregations. Given these challenges, a risk-based approach was adopted. A structured decision-making framework combined biological judgments concerning the ability of alternate closures in protecting important fishery species, and value judgments which required explicit trade-offs between protection, costs, enforcement and ecosystem benefits. The workshop identified two alternative closure regimes that were broadly acceptable to most participants and the Queensland Government implemented an annual closure regime of two 5-day closures around the October and November new moons.

19D Managing fish spawning aggregations
Thursday 12 July, 1530, Plenary Hall 2

Aggression and reproduction of Bolbometopon muricatum at Wake Atoll

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Recent comparisons between pristine versus impacted communities suggest pristine systems may be dominated by apex predators, yet the ecological role in these communities of non-predatory but large and highly vulnerable species such as the giant bumphead parrotfish (*Bolbometopon muricatum*) remains unclear. Overfishing has lead to low population densities and avoidance of humans throughout its range, contributing to its status as a Candidate species under the US Endangered Species Act. At sites where B. muricatum is abundant it may be a keystone species affecting coral community structure and sediment transport, thus additional research on its life history and ecology is critically needed. We studied spawning site characteristics and reproduction of *B. muricatum* at Wake Atoll, a relatively pristine environment and de facto marine reserve, and encountered high densities [297 individuals km-2 (SE 96)] that were easily approachable. From 12-25 August 2011, we conducted 100 h of snorkel and scuba observations utilizing HD video and GPS to record reproductive behavior and to track fish movements. Two different spawning sites were identified where we witnessed extraordinary displays of aggressive behavior between males. The social and mating system was determined, together with spawning site characteristics such as timing of spawning, persistency of aggregations/spawning groups, sex ratios and aggregation size at spawning sites, and movements of fish at spawning sites. Results provide critical life history information for this species and underscore the importance and utility of no-take reserves and isolated locations protected from fishing for the study of natural baselines in marine communities.

19D Managing fish spawning aggregations
Thursday 12 July, 1500, Plenary Hall 2

Conservation and management of grouper spawning aggregation sites: adaptive strategies based on fish movement patterns

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Most large groupers (Serranidae) form annual spawning aggregations (FSA) at predictable times and locations; a life-history trait that makes them extremely vulnerable to over-fishing. Seasonal or permanent fishery area closures can provide effective protection, but defining biologically relevant boundaries is difficult due to limited knowledge of the movement and migration patterns associated with spawning. The aim of this study was to compare the spatial and temporal patterns of movement and migration of groupers at spawning aggregations in the Caribbean and Pacific. Surgically implanted acoustic transmitters were used to track the detailed movements of four species of grouper in the US Virgin Islands (*Epinephelus striatus*, *E. guttatus*, *Mycteroperca venenosa*, and *M. tigris*) and three species in Pohnpei, Micronesia (*Epinephelus polyphekadion*, *E. fuscoguttatus* and *Plectropomus areolatus*) using a large array of 40 acoustic receivers that were strategically placed around two FSA sites. Data indicate that distance travelled was positively related to fish length and that these species commonly swam 1 to 3 km in a few hours and could cover 15 km or more in a 24 hr period. Some differences in spatial patterns of movement were detected between reef types in the Caribbean and Pacific but in most cases movements of tagged groupers carried them outside the existing protected area boundaries and exposed them to fishing mortality on a daily basis. Using the information from this study we can recommend general guidelines

for establishing spatial requirements for each species around spawning aggregation sites that can greatly increase levels of protection.

19D Managing fish spawning aggregations
Thursday 12 July, 1645, Plenary Hall 2

The right time and place: currents and Nassau grouper spawning

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There is almost nothing known about the fate of fish larvae born on spawning aggregations from the time of spawning to settlement, yet the location of the aggregation site must be important in determining their fate. While aggregations always form in the same place and at the same time in part to assure a large number of adults will congregate for spawning, oceanographic patterns of dispersal and retention of the larvae may provide a driving force for the selection of specific spawning locations. During the winters of 2008, 2009 and 2011 we deployed Surface Velocity Profile drifters at the Nassau grouper spawning aggregation site on Little Cayman Island, British West Indies. To determine initial trajectory paths off the aggregation, each night during the aggregation period a single drifter was deployed, then recovered 12 hours later. In contrast to the path taken on nights prior to spawning, on the night of peak spawning in each year there was substantial eddy formation near the aggregation site. This repeated pattern suggests an oceanographic-based 'importance of place' for the aggregation site that may result in local recruitment. This would mean that local aggregations of fish are directly responsible for the long-term survival of local populations, and that regional conservation efforts should focus on protecting as many spawning aggregations as possible. Our work gives substantial credence to the need to identify and protect specific locations because they are unique and critical to the long-term survival of the many species that aggregate there.

19D Managing fish spawning aggregations
Thursday 12 July, 1215, Plenary Hall 2

Reproductive movement and fisheries vulnerability of brown-marbled grouper, *Epinephelus fuscoguttatus*

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Brown-marbled grouper, *Epinephelus fuscoguttatus*, were tagged with acoustic and conventional spaghetti-type tags at a multi-species fish spawning aggregation (FSA) site in Pohnpei, Micronesia, to establish patterns of reproductive movement, residency and spawning seasonality. Results confirmed a 3-month peak reproductive season, the use of common reproductive migratory corridors, and sex-specific variations in residency and movement that may affect fisheries vulnerability. During the study, spawning aggregations formed and persisted over ca. 12 days prior to full moon in each month of the spawning season, which coincided with seasonally low and relatively stable seawater temperatures. Some males frequented the aggregation site during each month of two consecutive spawning seasons. Most females were present during only a single month of the spawning season, with visitation months consistent among years. All males arrived several days prior to females. Some individuals displayed inter-annual differences in the pattern of reproductive migration, suggesting possible changes in home range locations. Nearly two-thirds of tagged fish were relocated or recaptured within 11 km of the aggregation site, with a maximum detected distance of 26 km and a minimum estimated catchment area of 100-175 km^2. Findings highlight the need for a combined approach to management that prohibits the capture and sale of reproductive adults, and area protection of spawning sites and reproductive migratory corridors during the spawning season.

19D Managing fish spawning aggregations
Thursday 12 July, 1130, Plenary Hall 2

Assessing the vulnerability of fish populations to targeted aggregation fishing

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Reef fishes that form spawning aggregations vary considerably in terms of the intrinsic vulnerability to fishing that is conferred by aspects of their life history, sexual pattern and aggregative mode. However, population susceptibility to aggregation fishing depends on

numerous extrinsic (socio-economic) factors that are fishery specific. We identified indicators of intrinsic and extrinsic vulnerability and developed a framework for assessing the relative vulnerability of reef fish populations subjected to aggregation fishing. Seven intrinsic and six hierarchical extrinsic indictors were combined as indices, with the former tested on independent datasets and the latter scored by expert opinion, and the framework was evaluated for 11 aggregation fisheries in the western Indian Ocean. The intrinsic vulnerability index was positively correlated with reef fish population declines in a case study site but was unable to predict IUCN status for aggregative spawners assessed. Aggregation fishing was a significant driver of population status in more than half of the rabbitfish and grouper fisheries assessed. Selectivity and management regime were important determinants of the relative vulnerability of rabbitfish fisheries. Grouper populations targeted by live reef fish food fisheries were particularly vulnerable, as constraints to accessibility were overcome and demand and storage capacity were not limiting. In three of the assessed fisheries, for which independent data on population or aggregation status were available, the framework predictions were largely validated. While indicators and the framework require further validation, the development and use of such tools offers potential for rapid identification and prioritization of precautionary management measures in data-limited contexts.

19D Managing fish spawning aggregations
Thursday 12 July, 1030, Plenary Hall 2

Local knowledge for aggregation management

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Local and traditional knowledge on the locations and timing of reef fish spawning aggregations is extremely valuable for research, and can underpin locally supported management. In some tropical island communities, this local knowledge has been handed down through generations. However, in Australia, on the Great Barrier Reef, knowledge and understanding of the locations and timings of spawning aggregations, such as for common coral trout (*Plectropomus leopardus*), humphead Maori wrasse (*Cheilinus undulatus*), and Flowery cod (*Epinephelus fuscoguttatus*), has only been recent. Fisher knowledge is not based on historic and traditional fishing, and many fishers either have little understanding of spawning behaviours, or guard this information as business intelligence. Management of spawning aggregations on the Great Barrier Reef has been developed using broad scale fisheries and marine protected area management tools. Options and considerations for the use of fine scale or broad scale management approaches depending on local knowledge are identified.

19D Managing fish spawning aggregations
Thursday 12 July, 0930, Plenary Hall 2

How are we doing so far? A spawning aggregation report card

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Since the 1980s the exploitation of reef fish spawning aggregations has intensified, driven by growing commercialization of tropical coastal resources. An assessment of the management and exploitation history of reef fish spawning aggregations (FSAs) was conducted on ten of the best known FSAs. Lessons learnt point the way to more effective management of FSAs and aggregating species in general. Key findings were: (1) enforcement is a major challenge and poaching a major issue, (2) priority and capacity for reef fish management is very low in general, (3) follow-up monitoring after management is difficult and typically poor or non-existent making adaptive management a challenge, (4) aggregations are disappearing without management, (5) failure to protect aggregations leads to introduction of an ever-growing suite of management measures as populations continue to decline, and (6) loss of aggregations compromises associated fisheries. The assessments suggest that so far we are doing badly and that, among other things: (1) protection of FSAs as a sole measure is insufficient to halt declines, (2) MPAs around FSAs are often too small or incorrectly placed, (3) multiple management measures, that include an overall control of effort on the fishery of the target species and monitoring, are usually needed, (4) economic analyses of the benefits of aggregation protection are needed, (5) long-term commitment to management and wide engagement across interested sectors is necessary, and (6) FSAs should be completely protected from exploitation as a default measure, with exploitation only permitted if adequately controlled.

19D Managing fish spawning aggregations
Thursday 12 July, 1700, Plenary Hall 2

The science, politics, and conservation of Cayman Island Nassau grouper

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In 2003 the Cayman Islands government protected all known current and historic Nassau grouper (*Epinephelus striatus*) spawning sites. This move was motivated by the 2001 discovery and rapid depletion of a large spawning aggregation (~7000 fish) on the west end of Little Cayman. However, spawning site protected areas were established under a 'sunset' provision; that is, their effectiveness must be demonstrated by the end of 2011, or they will be revoked. Since the establishment of spawning site protections, the Reef Environmental Education Foundation (REEF) and the Cayman Islands Department of the Environment (DoE) have partnered to run the Grouper Moon Program, a multifaceted effort to both establish the scientific justification for grouper conservation and convey these findings to the general public. I will discuss the broad suite of efforts the Grouper Moon Program has made to promote grouper conservation in the realms of science, politics and education. I will also discuss political obstacles faced by the program, and lessons learned through the program's ongoing efforts to promote conservation laws directed at spawning sites.

19D Managing fish spawning aggregations
Thursday 12 July, 1000, Plenary Hall 2

A fishery-dependent assessment of fishes at risk from aggregation fishing

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Aggregating fishes present a unique challenge for fishers and managers as aggregation fishing can be economically rewarding yet lead to overfishing and population collapse. Many coral reef fish form aggregations for spawning and some high profile fisheries collapses provide a warning against the potential effects of aggregation fishing. However, locating and assessing the vulnerability of coral reef fish spawning aggregations to fishing is problematic due to a paucity of appropriate data. In this paper we present a method for interrogating commercial fishery logbook data that provides a robust quantitative assessment of the relative vulnerabilities of a serranid, a lethrinid and a scombrid to fishing. The advantages of this approach are that it captures all areas of operation of a spatially complex fishery, and considers the complete annual cycle of fish and fisher interaction. The Reef Line and Pelagic Line Fishery operate across nine degrees of latitude on the Great Barrier Reef, Australia. Both fisheries operate year round and seasonal spawning closures were introduced in 2004. A recent management review of the seasonal spawning closures occurred in response to socio-economic hardship imposed on fisheries stakeholders, though in the absence of any quantitative assessment of the vulnerability of targeted fish to increased harvest and hence risk during spawning. The method provided no clear evidence of increased vulnerability of serranid (*Plectropomus leopardus*) or lethrinid (*Lethrinus miniatus*) to fishing during spawning seasons or closure periods, though the pelagic scombrid (*Scomberomorus commerson*) is clearly more vulnerable to fishing during spawning. Management implications are discussed.

19D Managing fish spawning aggregations
Thursday 12 July, 1230, Plenary Hall 2

Saving the undersea giants: management of exploited grouper spawning aggregations

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Many species of coral reef fish, including high-value species such as coral trout and other grouper, form Fish Spawning Aggregations (FSAs), where tens to thousands of adult individuals aggregate primarily for the purpose of reproduction. These FSAs are particularly attractive to fishers due to the relatively high densities of target species and their temporal and spatial predictability. Consequently, FSAs are extremely vulnerable to overfishing; a recent meta-analysis found that 79% of worldwide, and 44% of Indo-Pacific coral reef FSAs studied were in decline or had disappeared entirely. Despite these alarming rates of decline, few spawning aggregations are under effective, scientifically sound management. Currently, the most common form of management applied to FSAs is to temporally or spatially restrict fishing effort. However, these efforts are often impeded by a lack of knowledge about the relevant spatial scales for management; how far larvae disperse, how far adults move to reach the aggregation, home range size and juvenile and sub-adult habitat requirements. In addition to this necessary ecological information, any persistently effective management must consider at what spatial scales the

socioeconomic institutions relevant to management, such as local marine tenure systems, operate. This study will evaluate relevant spatial scales of management for a large multi-species spawning aggregation on a coral reef in New Ireland, Papua New Guinea. The study will result in rigorous, science-based recommendations for management that will improve food security, ensure fisheries sustainability, and benefit populations of both fish and fishers.

19D Managing fish spawning aggregations
P214

Theme 20. Restoration of coral reefs

20A. Restoration of coral reefs

Reef Dome: a novel model for coral reef rehabilitation

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Twelve years of results from coral restoration experiments indicated that a concrete mixture is the most suitable material to be used in reef rehabilitation. The mixture was cast onto an extended plastic net in a number of stages, starting from the outside and then from the inside, until the mixture fully covered the model steel structure (Dome like). To the outer cement layer, attracting materials were added, providing a source of calcium carbonate and natural pigments. The artificial reef experiment was designed to test the intensity and diversity of recruitment for different coral species on this artificial substrate, using four different models. A total number of 255 coral recruits were recorded on the external surface of the four models over two consecutive, year long, experimental periods. These 225 coral recruits (Zoanthiniaria) represented 28 species belonging to 17 genera. In addition, 14 non-scleractinian coral (Alcyonacea) recruits were also recorded on the surface, with another 16 recruits from *Milleporina*. The taxonomic composition, spatial distribution and abundance, and percentage of mortality of different coral species' recruits were obtained. Also, comparisons in recruit density and diversity among the four different models, space partitioning between coral genera and species diversity were carried out.

20A Restoration of coral reefs
Wednesday 11 July, 1755, Sebel Bluewater

Bioreeftek as a natural product, new concept for reef rehabilitation

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Building artificial reefs for reef rehabilitation has, until now, been relatively expensive. We have developed a method for reef rehabilitation using coconut shells called Bioreeftek. These reefs have been deployed in several locations, and then monitored using timed swims and a visual census method. The results have shown successful settlement of coral larvae, coral and the other associated species (*Acropora*, *Montipora*, *Porites*, Octocorallia, etc). This reef material is relatively cheap and easy to find in Indonesian coastal areas. Using coconut shells is a new concept for artificial reefs and is appropriate in Indonesia to support the rehabilitation of coral reef ecosystems.

20A Restoration of coral reefs
Wednesday 11 July, 1740, Sebel Bluewater

Restoration of a vessel grounding site in Gulf of California

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On 22 September 2001, the M/V Lázaro Cárdenas II, a 202 m oil tanker, grounded on a coral reef dominated by the ramose genus *Pocillopora*, at San Lorenzo Channel, southern Gulf of California. The event impacted a total area of 882 m^2. A week later, the passing of hurricane Juliette dispersed the coral rubble to the adjacent coral reef, affecting additional 7625 m^2. After damage assessment, a thorough removal of live and dead coral fragments was done in both areas, and by 2002 thirty artificial structures (modules) of rock and concrete were deployed in the grounded site as a mitigation action, in order to affix living fragments of *Pocillopora* spp. To determine the success of the modules as appropriate habitat replacement, a monitoring program was established in June 2004. The program focused on the quantification of the survival and growth of transplanted fragments, and also was useful to assess local coral recruitment. It also evaluated the use of the restored area by algae, invertebrate and fish communities by examining composition, richness and density over time and by comparison to the adjacent reef. After seven years, 70% of the cemented fragments are alive, and the growth rates are comparable to those in natural reefs. Recruitment of settlers was high, and the dominant colonizer was *Porites*. Finally, the community analyses show a rich biota associated with the restored area, but nevertheless the assemblages are still distinguishable from natural reef. The results and perspectives of the restoration on studied reefs are discussed.

20A Restoration of coral reefs
Wednesday 11 July, 1630, Sebel Bluewater

Propagation of sexually-derived coral recruits for active coral reef restoration

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The sexual propagation of corals for use in coral reef restoration is gaining interest as a means to offset losses in biodiversity and ecosystem services due to the degradation of reefs by anthropogenic impacts, natural disturbances and global climate change. The Mexican Caribbean has suffered a dramatic loss of coral cover (80% in 35 years) and research is underway to actively restore coral reefs in this region. To be successful requires a multidisciplinary approach and collaborative effort that incorporates knowledge about a) population genetic structure (clones versus recruits); b) basic reproductive biology of corals such as their spawning times, reproduction type and whether the corals spawn gametes or larvae; c) developmental requirements of the embryos and larvae; c) substrate type and light requirements for settlement; d) symbiosis to determine the *Symbiodinium* type(s) that should be used for inoculation of the corals and how this interaction may change over the coral life-cycle; e) raising marine wildlife in captivity to grow out the recruits under controlled versus semi-controlled conditions taking into account light, water flow, temperature and feeding; and f) community succession and competition studies to determine the optimum point at which coral recruits should be explanted into the coral reef ecosystem. Critical for the success of such endeavours is an affiliation with marine park managers and local stakeholders. The advances in all of these lines of research will be discussed with recommendations on the most critical areas of future research in active coral reef restoration.

20A Restoration of coral reefs
Wednesday 11 July, 1030, Sebel Bluewater

Coral transplantation success and dynamics of community assembly

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A coral transplantation experiment was conducted in Bolinao, Pangasinan in the western Philippines with the objective of restoring coral cover on a degraded reef flat. *Montipora digitata* (Order Scleractinia) is a common reef flat species observed to thrive on sandy to sandy-rubble substrates under high levels of light and turbulence. The same conditions were observed in the experimental site. The species also propagates successfully by natural fragmentation. The experiment compared the more mobile and easily fragmented small (fist-sized) with large (approximately 0.20m in diameter) transplants. Transplants were collected from the same reef area that harbored naturally occurring dense patches of *M. digitata*. Empty plots which served as controls as well as donor plots or natural colonies were also monitored regularly. Data from the experiment were used to develop an agent-based model to simulate long term trajectories as well as derive insights on community assembly. There was no significant difference in terms of *M. digitata* cover between the small and large transplants after two years. Both persisted and increased cover by 0.4 percent for the small transplants and 0.47 percent for the large transplants, respectively. An opposite trend of decreasing cover was observed among the natural colonies. The absence of natural recruitment of *M. digitata* was observed in the control plots. An additional positive result of the field experiment was the survival of *M. digitata* colonies outside of the experimental plots. The agent based model provides initial insights into the dynamics of community assembly in the context of restoration.

20A Restoration of coral reefs
Wednesday 11 July, 1230, Sebel Bluewater

Thermal tolerance as a factor in Caribbean *Acropora* restoration

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Ongoing work in Belize focuses on the identification and propagation of thermally tolerant *Acropora* genotypes. The work has created *in situ* gene bank nurseries of the threatened coral species: *A. cervicornis*, *A. palmata*, and *A. prolifera*. Three nursery methods were used: mesh A-frames, suspended ropes, and cement discs affixed to mesh trays. Eleven nurseries were established, planted with a total of 783 corals of 33 genotypes. Genetic analyses were conducted for both algal symbionts and coral hosts. All outer reef corals sampled had clade A symbionts, while inner reef corals had a mix of clade A and clade D. Several genotypes with clade A bleached severely while others did not, indicating that the coral host is an important factor in bleaching resilience. Corals from inner reefs grew about twice as fast as those from the outer reef. A-frames worked well for comparing genotypes, while for increasing biomass, ropes worked best for *A. cervicornis* and *A. prolifera*, and the cement disc method worked exceptionally well for *A. palmata* and *A.*

prolifera but not for *A. cervicornis*. All colonies were trimmed at 7-9 months and again at 12-18 months to produce fragments for transplanting to restoration sites. Over four thousand second generation corals were planted to reef patches within Laughing Bird Caye National Park, where severe bleaching, disease, and hurricanes had extirpated the *Acropora* corals. A genetically diverse *Acropora* population containing thermally tolerant genotypes has now been restored, which in turn should facilitate the restoration of sexual processes for natural recovery.

20A Restoration of coral reefs
Wednesday 11 July, 1415, Sebel Bluewater

Successful mass culture of corals using sexual reproduction technique in Thailand

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In Thailand, mass culture of corals using a sexual reproduction technique was successfully developed. This method was initiated by the Reef Biology Research Group, Department of Marine Science, Faculty of Science, Chulalongkorn University in collaboration with the Plant Genetic Conservation Project under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn, the Royal Thai Navy, and Akajima Marine Science Laboratory in Japan. At present at least 8 coral species can be cultured. After the gametes of corals were collected and fertilized, planula larvae were induced to settle on substrates. The fertilization rates of gametes ranged between 92-97%, and the settlement rates were 49.5-76%. The juvenile corals were reared in a land-based rearing system for at least 1-2 years before they were transplanted back to natural reefs. The survival rate of juvenile corals after transplantation into the sea was more than 50%, and the growth rates of transplanted juvenile corals were higher than those in the hatchery. In addition, during the April-June 2010 bleaching event, we found that juvenile corals that were cultured from sexual reproduction and later were transplanted into the sea prior to April 2010, were rarely bleached. At present, with the collaboration of the Department of Marine and Coastal Resources of Thailand, the coral culture technique using sexual reproduction has been used as one of the techniques for coral restorations in Thailand.

20A Restoration of coral reefs
Wednesday 11 July, 1145, Sebel Bluewater

Reef flat recovery following large-scale removal of invasive algae

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The invasive alien alga (IAA), *Avrainvillea amadelpha*, has fundamentally altered the extensive, shallow reef flats of Maunalua Bay, Hawaii, transforming a diverse, productive mosaic of native algal and seagrass communities into a sediment-laden monoculture of alien algae. Starting in April 2010 and finishing in May 2011, the local community and The Nature Conservancy, along with government, academic, and business community partners, removed 23 acres and over three million pounds of invasive algae. A coalition of scientists monitored the recovery of local physical and ecological processes and native species within the project area to determine the viability of large scale IAA removal as a reef flat restoration technique in Hawaii. Following removal, cover of *A. amadelpha* dropped from 56.9 ± 2.7% to 4.2 ± 1.1%. Initially silt trapped by IAA remained entrained within the project area, but eventually began to flush from the bay following a series of high wave events. Sediment depth and amount of silt significantly decreased following IAA removal. Native algal diversity has significantly increased since IAA removal. Cover of native algae has gradually, but not significantly, increased following IAA removal, suggesting recovery time for this community is longer than twelve months. Overall, removal of *A. amadelpha* has successfully restored the natural processes to the area cleared of IAA. While recovery of the native community has progressed at a slower than anticipated rate, data suggest recovery is occurring, and that large-scale removal of IAA may be a viable restoration option for reef flat communities in Hawaii.

20A Restoration of coral reefs
Wednesday 11 July, 1500, Sebel Bluewater

Survival and fecundity of *Eunicea flexuosa* (Cnidaria: Octocorallia) transplants

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Octocorals are important components of many reef benthic communities, and efforts to restore populations following damage events and relocating colonies preceding permitted

activities is becoming part of regulatory processes. Because many octocorals have regenerative capabilities ideal for removing branch clippings, they may make excellent donors for restoration efforts. But do these transplanted clippings survive and are they reproductive? The purpose of this study was to examine the effect of fragment size, fragmentation timing, and transplantation on the survival and fecundity of *Eunicea flexuosa* clippings and donor colonies. *Eunicea flexuosa* clippings, 20 cm in height, were transplanted to a ship grounding site offshore southeast Florida in April 2010 and November 2010. Samples were collected during the June through September spawning months in 2010 and 2011. The fecundity of the April transplants was similar to that of donors and controls in June and July 2010, however transplants had fewer, larger oocytes (> 600 µm) in August 2010. In June 2011, immature oocytes were found in the April (< 400 µm) and November (< 300 µm) transplants. No oocytes were found the following months. Transplantation stress may explain the increased egg volume in the April transplants in 2010, while a re-allocation of energy resources towards growth may account for the loss in fecundity of transplants in 2011. This study highlights the importance of evaluating fragment size and collection time in promoting survival and propagation of transplanted octocorals following damage and prior to marine construction events.

20A Restoration of coral reefs
Wednesday 11 July, 1515, Sebel Bluewater

Acropora restoration program in Mexican Marine Protected Areas

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The *Acropora* Restoration Program is developed in the Gulf of Mexico since 2007 in ship grounding sites of the Port of Veracruz and carried out jointly by Oceanus, AC, Aquarium of Veracruz and Veracruz Reef System National Park. Early stages (I-III) include the rehabilitation of sites of *Acropora palmata*. To date 4,000 colonies have been transplanted to the fore reef on one hectare of Anegada de Adentro, with an approximate density of 2 colonies per square meter. On this site live coral tissue has increased by approximately 50 m^2 as a result of transplantation. In 2011 this program began to be replicated in other protected area in the Gulf of Mexico: Alacranes Reef National Park; and in two protected areas of the Mexican Caribbean: Xcalak Reefs National Park and Biosphere Reserve Banco Chinchorro with support of Oceanus, A.C. and the Federal Government. In one protected area, restoration sites have been designated as 'special management zones'. Under this regulation fishing is not allowed, the local community can participate in the program activities and, in addition to restoration, members of the local community can make use of the infrastructure (after training) to take tourist tours based on the tasks of the program. The program in Mexico now has 5 functional source nurseries from different parental colonies and 20 nurseries for stabilization, with a production capacity of 2500 coral colonies each year. The goal in these early stages is the rehabilitation of 5 sites: 2 in the Gulf of Mexico and 3 in the Mexican Caribbean.

20A Restoration of coral reefs
Wednesday 11 July, 1445, Sebel Bluewater

An assessment of reef recovery following ship groundings in Florida

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The Florida Reef Tract exists along the eastern shelf of the United States from the Dry Tortugas northward through the Florida Keys and southeast (SE) Florida. The SE reefs lie offshore a highly urbanized area and are impacted by commercial and recreational fishing and diving, marine construction, and major shipping. Heavy ship traffic associated with one major port has resulted in ten large vessel groundings between 1994 and 2006. The condition of seven grounding sites of differing ages was compared to undamaged reference sites, in order to provide resource managers with information on reef recovery status and factors which may affect recovery. This study examined density and size class distribution of stony corals and gorgonians (including recruits), percent cover of major benthic community groups, and physical characteristics including substrate types and topographic complexity. Only limited recovery was seen within the groundings sites. All grounding sites had reduced stony coral and gorgonian percent cover, species diversity, and size class distributions remained greatly skewed towards smaller colony sizes. Grounding sites had greater percent coverage of unconsolidated rubble substrates and were less rugose (flatter) than reference areas. This

study provides evidence that recovery following ship groundings is an extremely slow process and may lead to an altered community. Recovery is greatly inhibited by the presence of unconsolidated substrate which provides a poor habitat for survival and growth of stony corals and gorgonians. Thus, activities following future grounding events must include greater efforts to restore the physical characteristics of the damaged reef.

20A Restoration of coral reefs
Wednesday 11 July, 1645, Sebel Bluewater

Closing the circle: rearing corals from eggs to adults for reef rehabilitation

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There are two methods for producing corals that can be used for transplantation during reef rehabilitation efforts. They can be produced asexually from fragments; or they can be produced sexually by collecting larvae or gametes from colonies, rearing them until settlement or until they have reached a suitable size for transplantation to the reef. The former method has been practised for several decades and the techniques (at least in terms of rearing large numbers of asexual fragments) are well established for many species and locations. The latter method is still largely at an experimental stage both in terms of the optimal methods for rearing and settling larvae en masse and in terms of the best practices for transplantation to the reef. Sexual propagation will result in higher genetic diversity compared to asexual propagation and has the potential to produce very large numbers of juvenile corals if the normally high levels of early mortality are reduced. Larval rearing should also result in less damage to existing reefs as donor colonies can be returned to the wild after spawning. Larval rearing however is more costly and labour intensive compared to asexual techniques. It also requires additional expertise, facilities and accurate information on spawning seasonality and timing. Here I will provide an overview of the current techniques being used to rear corals for reef rehabilitation using sexual reproduction and will provide examples from research carried out at sites in the Philippines, Micronesia and Singapore.

20A Restoration of coral reefs
Wednesday 11 July, 0930, Sebel Bluewater

Success of outplanted *Acropora cervicornis* colonies based on genotypes and attachment methods

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Populations of *Acropora cervicornis* have suffered dramatic declines throughout the entire Caribbean since the 1980s, leading to the listing of this species as 'Threatened' under the Endangered Species Act in 2005. Due to the fast growth of this species, nurseries have been identified as potential tools for its recovery and as means to restore reefs that have been damaged by physical impacts. In Guayanilla, Puerto Rico, at the site of the T/V Margara grounding, three different genotypes of *A. cervicornis* were outplanted using three different attachment methods (cable ties, epoxy and stabilization of colonies in reef crevices using no foreign materials). Colonies were monitored at six months and one year after being outplanted to the reef. Data were collected on colony stability, percent tissue mortality, and overgrowth of the colony onto the reef substrate. Binomial logistic regression showed that epoxy stabilization was more effective than the cable ties, although both methods were more effective in promoting fragment recovery than stabilization using no foreign materials. There were also differences in success between genotypes. Overall tissue mortality was low. The results of this study provide important insight for future nursery operations. Although some genotypes may be more successful than others, it is still important to include as many genotypes as possible in restoration efforts to help increase genetic diversity on the reefs in the interest of increasing the potential for successful sexual reproduction. In addition, attachment methods such as epoxy should be used when possible to increase the survival of transplanted corals.

20A Restoration of coral reefs
P216

Marine silviculture: long term monitoring of farmed corals' transplantation

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Coral reefs are declining at an alarming pace as increasing anthropogenic activities and human-amplified global changes have significantly altered their ability to cope with disturbances. The failure of traditional restoration techniques have clarified that active measures are now crucial to impede the reefs' further decline and to ensure the persistence of this habitat. Inspired from silviculture rationales, a new concept, 'gardening coral reefs', has been proposed. This two step methodology consists of the generation and farming of large

stocks of new coral colonies in nurseries prior to their transplantation onto degraded reef sites. Like in terrestrial forestation, transplantation of nursery-grown corals carries ecological-engineering benefits, such as the construction of rehabilitated reefs with particular coral coverage, associated species' compositions and emerged seascape. Nursery-grown corals of seven branching forms were transplanted on a degraded zone of Eilat's Reef in three stages (November 2005, May 2007, September 2008). The colonies showed high survivorship, fast growth rates and attracted invertebrates and fish. To further evaluate post-transplantation performances we monitored reproductive efforts of one of the transplanted species. Surprisingly, transplanted colonies showed better reproductive capacities than natal colonies during >4 post transplantation years. A higher percentage of farmed colonies released larvae as compared to naturally grown colonies. Gravid transplants also shed more planulae per colony, yielding higher numbers of total planulae. Thus, nursery-grown corals not only reinforce the local coral community but may also be used to enhance reef resilience by contributing to the larval pool, forming an engineered larval dispersal instrument for reef rehabilitation.

20A Restoration of coral reefs
Wednesday 11 July, 1215, Sebel Bluewater

Coral relocation as a mitigation tool for dredging works in northern Jamaica

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Royal Boskalis Westminster executed the dredging and reclamation works required to develop the Falmouth Cruise Ship Terminal in Trelawny, Jamaica. To preserve benthic marine resources, a large-scale environmental mitigation plan was conducted and the magnitude of this project has made it the largest coral relocation exercise in the world to date. Maritime and Transport Services Limited (MTS) executed this relocation project, which started in August 2009, and by April 2010, 147,947 items (8,975 soft coral; 137,789 hard coral; and 1,183 sponges) were successfully relocated. An additional 2,807 sea urchins, mainly *Diadema* were relocated from the dredging area, as well as numerous sea cucumbers, hermit crabs, conchs, sea stars and lobsters. To determine the biological success of the relocation exercise, time series photographs of 400 colonies were taken on three occasions: October 2009, April 2010 and April/ May 2011). In April 2010, partial colony mortality and algal overgrowth were observed but no total colony mortality was found. In April 2011, cases of total colony mortality were observed, as well as new incidences of disease; but preliminary results indicate that 80% of the colonies relocated in 2009 were accounted for in 2011.

20A Restoration of coral reefs
Wednesday 11 July, 1530, Sebel Bluewater

Device development for coral growth propagation combining mineral-technology and weak-electrochemical method

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Two elemental processes have been reported as effective for coral restoration; these are a) electrochemically coated surfacing which provides a good substrate for coral larvae settlement and b) weak impressing of electric density around 50mA/m^2 which is effective in coral implantation for growth promotion at early stages. Here, we will report on the development of the combined system of applying these two processes. On bleached coral reefs, a decrease in new larval supply as well as an increase in predation pressure on young corals, is expected. Accordingly, restoration from bleaching specifically requires the following processes; a) effective settlement of larvae on the new substrate and b) rapid growth of juveniles after settlement to a certain size. Electrochemical treatments could promote both processes. But, treatment of the two processes needs quite different electric density at different life stages. Electric-coated surfaces should be produced with a relatively high electric current before coral spawning, while juvenile growth can be promoted only under a weak electric field after settlement. We examined two possible ways for combining the two processes; a) producing the substrates beforehand in the laboratory with their surface mineral-coated and then setting them on the devices with a weak electric field in the sea before spawning, and b) producing devices which can alter their electric density automatically, and setting the devices in the sea from the beginning, assigning high current density for mineral-coating at first and then changing to a weak electric-density before spawning. Field observations were conducted in Okinawa. Preferable results were obtained from the initial propagation of coral growth.

20A Restoration of coral reefs
Wednesday 11 July, 1750, Sebel Bluewater

Fish colonization on reefballs over 9 years (2001-2009) at Ratatotok Peninsula in North Sulawesi, Indonesia

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Reefballs are a concrete artificial reef unit used in over 56 countries for a range of applications. In 1999, the gold mine operator PT Newmont Minahasa Raya initiated an artificial reef program to provide an incentive to protect local marine resources from bomb fishing, cyaniding and other unsustainable practices. From 1999 to 2002, around 2,500 units were deployed in 6 locations along the coast of Ratatotok Peninsula and Buyat Bay, North Sulawesi, Indonesia. Monitoring was conducted annually from 2001 to 2009 for Target and Indicator species of fish. In 2009 this study identified 13 families, 30 genera, 83 species and 4,171 individuals inhabiting the reefs. Species richness and abundance steadily increased on all Reef Ball reefs from 2001 to 2006 and stayed steady through 2007, but declined in 2008 and increased again in 2009. The fastest growth, highest diversity and numbers of individuals were found on these three reefs. Richness and abundance decreased on these 3 reefs in 2008. Factors affecting the fish colonization in the RB of each station include distance to natural coral reef, substrate types, stability of coral reef ecosystem around reefball and configuration of reefball.

20A Restoration of coral reefs
Wednesday 11 July, 1745, Sebel Bluewater

Octocoral reattachment strategies for successful restoration

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Octocorals are a prominent component of many coral reef benthic communities especially offshore southeast Florida. Octocorals are also dramatically impacted by anthropogenic stressors associated with coastal urban development. Their upright morphology relative to their small attachment point makes them especially vulnerable to impact by lines, cables, and anchor chains dragged along the seafloor. In late 2002 in southeast Florida, cables from an authorized dredging project mistakenly dragged across a reef surface dislodging and fragmenting numerous octocorals. This prompted a large-scale quantitative effort to investigate the effectiveness and success of different octocoral reattachment methods. In 2003, 453 octocorals from six genera were reattached using one of six reattachment methods: epoxy, nail and epoxy, drilled hole and epoxy, cement, nail and cement, and stainless steel pins. In early 2007, 387 colonies were found with an overall survival rate of 42%. By 2009 survival dropped to 32%. However colonies in all six genera within all six attachment treatments showed presence of a new holdfast. Six years after the initial reattachment effort, the pin method had the highest percent survival at 41% but the lowest attachment rate at 7%. The remaining methods had similar percent survival (21-39%) and attachment rates (22-32%), suggesting that several reattachment methods may be effective. Octocoral relocation and transplantation has become a required activity during damage event restoration and permitted impact minimization efforts. Continuing research on determining effective genus-specific reattachment methodologies is needed by resource managers.

20A Restoration of coral reefs
P217

Improving cost-effectiveness of coral restoration by optimizing coral rearing time

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With the rate of coral reef degradation increasing worldwide, active biological restoration by coral propagation and transplantation is an increasingly popular management strategy. There exists a variety of coral propagation techniques for reef restoration using fragments or juveniles reared from larvae, and these typically include a nursery phase to increase coral size to improve post-transplantation survival. Unfortunately, rearing corals for a prolonged period can incur high maintenance costs and there is a need for a framework that allows restorers to establish the cost-effective age or size to rear a coral to before transplanting it, based on the costs of the propagation technique used and predicted mortality rates of the coral species. Three methods of determining age/size-based mortality rates of *Pocillopora damicornis* were tested: 1) monitoring transplanted spats, 2) monitoring naturally-recruited spats and 3) monitoring naturally occurring corals - and evaluated based on effort, cost and reliability. Natural recruit mortality rate was significantly lower than the mortality rate of transplanted

spats (indicating an underestimation of transplant mortality), but was easier to obtain and more feasible for predicting transplant mortality rates for restoration purposes. A combination of methods (Method 2 and 3) that can be used to estimate mortality rates specific to their species or location of interest is proposed. A simple framework that estimates the most cost-effective coral rearing time before transplantation is then presented. The framework can be tailored to the needs of different projects, making it a potentially useful tool for coral reef restoration and cost-benefit analyses.

20A Restoration of coral reefs
Wednesday 11 July, 1000, Sebel Bluewater

Restoring Acroporid coral reefs in the US Virgin Islands

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Acroporid coral populations throughout the Caribbean and western Atlantic have drastically declined since the 1980's due to temperature induced bleaching, diseases, and hurricanes. The ability of Caribbean reefs to cope and recover from these natural disturbances and more localized, direct and indirect anthropogenic impacts has significantly been reduced over time. In an effort to enhance the resilience and structural complexity of U.S. Virgin Island (USVI) reefs, The Nature Conservancy's USVI program has established coral nurseries using American Recovery and Reinvestment Act funds. The nurseries house elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) coral fragments detached during storm events and vessel groundings. The fragments will be used to enhance genetic diversity, reverse population decline, and maintain ecosystem services at outplanting sites throughout the territory. This project will monitor colony survivorship (resistance to natural and anthropogenic stressors) and the re-colonization of reef-dwelling organisms at outplanting sites. Location based variations in responses of individual transplanted corals to environmental factors will be analyzed to determine the optimum habitat requirements for future coral recovery projects. The nursery program will increase local community awareness of the importance of coral reefs and benefit the scientific and habitat restoration communities. More importantly, the outreach and education through the ARRA nursery project, along with the establishment of the Virgin Islands Reef Resilience Program should create stewardship, behavioral and policy changes, and a reduction in the incidence of anthropogenic stressors impacting coral reefs in the US Virgin Islands.

20A Restoration of coral reefs
Wednesday 11 July, 1245, Sebel Bluewater

Manipulating topographic heterogeneity for enhancing diversity on coastal defenses

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The loss of topographic complexity is one of the most serious problems threatening the persistence of natural communities. Increasing urbanisation in Singapore has resulted in extensive replacement of natural habitats with man-made ones such as seawalls, jetties and breakwaters. These coastal structures, which are often erected on or near coral reefs, tend to support biological communities with low diversity; partly because they are less complex and heterogeneous compared to natural habitats. Relevant habitat structure is often a limiting factor for species diversity, especially at small spatial scales. To test if topographically more heterogeneous substrates will support greater biodiversity, we designed two types of concrete tiles with approximately equal surface areas, one structurally more heterogeneous than the other, plus a control tile made of granite. To quantify the amount and variety of space available, we created four different geometric designs and then used a simple algorithm with a fixed mean value to randomly vary the size, depth and spacing of each component for the heterogeneous tile design. The simple tiles had components with equal size, depth and spacing of the same fixed mean. The concrete tiles (n = 8) were then mounted onto steel frames which were in turn fixed onto granite seawalls (at two tidal heights) adjacent to coral reefs at two islands south of Singapore. After a year of colonization and monthly monitoring, they were collected and their assemblages were compared.

20A Restoration of coral reefs
P218

Disease dynamics and mitigation in restocked *Acropora cervicornis* populations

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Threatened species status under the US Endangered Species Act has fostered intent and cautious pursuit of active field nursery culture and restocking efforts for *A. cervicornis* in US reefs. Outplanting efforts in the Florida Keys have restored small populations on a

growing number of reefs. However, concerns remain regarding the health status and any potential health threat that might be posed by outplanted corals to wild stocks. This study conducted disease surveillance on six reefs with outplanted colonies and two sites with wild colonies in the upper Florida Keys from May-Sept 2011. Substantially higher disease prevalence was observed in the outplant sites (mean 7.8%, max 34.8% over seven surveys; acute outbreak conditions observed at 3 of 6 sites) compared to the wild sites (mean 3.5%, max 13.6%; no acute outbreak conditions). In addition, simple disease mitigation treatments were tested in the outplanted populations. Mitigation trials (namely, directly covering the tissue loss margin with an epoxy band and excising healthy portions of diseased colonies) yielded variable results with a small overall improvement in proportion of diseased branches with arrested tissue loss (compared to untreated control branches). However, both types of treatments applied at times and places with lower, baseline disease conditions appeared more successful than when applied during outbreak conditions. Ongoing work to characterize the particular disease conditions observed in the studied populations (via histopathological and molecular tools) are aimed to help interpret this variability in effectiveness of mitigation treatments and help target successful intervention efforts.

20A Restoration of coral reefs
Wednesday 11 July, 1400, Sebel Bluewater

Emergency coral response team ameliorates small vessel grounding damage in US Caribbean

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US reefs are impacted by 3-4 large groundings and hundreds of small incidents annually. In the aftermath of groundings, impacted corals are often broken, dislodged, or flipped over. These fragments are subject to abrasion, scour, and sedimentation, which ultimately result in death. Unchecked, these damages can result in additional coral reef loss and instability. However, if dislodged fragments can be stabilized shortly after physical impacts then the probability of survival increases substantially. In acknowledgement of existing limitations and in collaboration with local jurisdictions, NOAA has established an emergency response team that has been able to address the numerous impacts that are occurring annually. A notification network has been set up with the US Coast Guard, salvers, and the local communities. As a result, grounding reports increased from 10-15 per year prior to 2009 to an average of 60 per year. Early notification of incidents allows us to rapidly deploy staff to an incident in order to work with the vessel owners, salvers, and the USCG in order to minimize additional coral injuries during vessel extraction. Historically more coral impacts occur during vessel extraction than during the initial grounding. Rapid response to coral impacts allows for triage of broken corals and quick implementation of emergency restoration to prevent additional mortality to the corals or additional damage to the adjacent reef. Since 2009, the team has responded to 35 incidents involving physical impacts to coral reefs and stabilized and reattached over 20,000 corals.

20A Restoration of coral reefs
Wednesday 11 July, 1715, Sebel Bluewater

Scaling up *Acropora* nurseries in the Caribbean and improving techniques

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Coral reef ecosystems have been in a steady state of decline around the world. In the Caribbean, populations *of Acropora cervicornis* and *A. palmata* have suffered such a dramatic decrease that these species have been listed as 'Threatened' under the U.S. Endangered Species Act. It has been decided that given the decreasing size and low genetic diversity of Acroporid populations in the Caribbean, active population enhancement is warranted and *in situ* nursery programs need to be expanded and brought to production level in order to sustain a genetically diverse stock that is capable of either acclimation or recovery should other threats stabilize or subside. Traditionally, the majority of coral nursery programs have been small scale efforts. These efforts were expanded domestically in 2009 with new funding, but sites still relied predominantly on traditionally time intensive techniques. Since that time, NOAA's Restoration Center has been collaborating with a variety of partners to both improve and further scale up nursery operations in Florida, Puerto Rico and the U.S. Virgin Islands. New techniques have been developed that substantially improve colony survival and increase growth rates, while at the same time, make the nurseries more storm resilient, require significantly less maintenance and reduce costs. The expanded site capacity and gained efficiencies are allowing for implementation of a strategy that will see a significant increase in the number of genetically diverse outplanted corals. Approximately 15,000 corals will be outplanted across the region in 2012. With sustained funding, this number will continue to increase annually.

20A Restoration of coral reefs
Wednesday 11 July, 1700, Sebel Bluewater

Ex situ coral culture may prevent species extinction in Mauritius

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The reefs of Mauritius play a vital role in the protection of coastal areas, fisheries and tourism activities and in the preservation of biodiversity. However, the ever increasing rise of sea surface temperature, local anthropogenic impacts and various other stressors are contributing to their degradation. Numerous local coral species are facing rapid population decline and could be at risk of extinction. In 2008, we started the culture of various coral species in a land-based nursery to investigate their survival rates and growth potential. We established a nursery at sea as the control. Initially four species, *Acropora austera*, *A. selago*, *A. formosa* and *Pocillopora damicornis* were under culture. In 2009, we started the culture of other species such as *Montipora digitata*, *Porites palmata*, *Pavona decussata*, *P. cactus*, *P. danai* and *Galaxea fascicularis*. Four species which had suffered from drastic declines in abundance *Caulastrea connata*, *Stylophora pistillata*, *Heliopora coerulea* and *Plerogyra sinuosa* were cultured from 2010. We present here the results obtained over 1-3 years on the survival and growth rates of the cultured species. We demonstrate that it is possible to propagate and maintain various coral species in a land-based culture facility. Under rapid climate change, the *ex situ* culture of corals would most probably not save all corals from population decline and local extinction, but it would most certainly help to some degree in the conservation of coral diversity and its genetic resources, and the eventual re-establishment of some species into their natural environment.

20A Restoration of coral reefs
Wednesday 11 July, 1035, Sebel Bluewater

Experimental transplantation of corals using sexual reproduction in Manado, Indonesia

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We conducted a brief survey on the coral community structure and recruitment of *Acropora* in six sites around Manado, Indonesia in 2007. *Acropora* corals decreased drastically and recruitment was extremely low. To examine the future of *Acropora* corals around Manado, we assessed the reproduction potential of these corals using coral settlement devices (CSD) and marine block (MB) plates. As a result, no mass spawning was observed in 2007. However, spawning peaks were observed from February to June and after October, the former being larger in scale. Within a year of settlement (February-May of the following year), the corals had grown to a size of 13.4 ± 5.86 mm. Two years after settlement, the corals were approximately 39.9 ± 13.0 mm, and it was easier to differentiate between groups settled at different times. We also attempted to apply the coral restoration method using sexual reproduction developed and successfully conducted in Japan's largest coral reef 'Sekisei Lagoon'. Twenty-four CSD cases (each contains 120 CSDs) were deployed at the breakwater of Manado coast in May 2009 and transported to Bunaken Island in August to prevent biofouling and sedimentation. Ten MBs (1 m x 1 m, height 0.5m) were deployed on a sandy bottom at 7-m depth of Likupang in November 2010. Two hundred and eight CSDs with growing corals, collected from Bunaken Island, were transplanted onto the MBs. Results of periodical observation after the transplantation will be reported.

20A Restoration of coral reefs
Wednesday 11 July, 1115, Sebel Bluewater

Growing corals in line and floating nurseries at Tayrona Park

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Caribbean Colombian coral reefs are facing, as most Caribbean reefs, high degradation as a result of multiple natural and anthropogenic impacts. Although there is a need for reducing local stressors, the capacity of national agencies to do so is limited, and the need for active restoration has been identified. In 2010, three institutions (government, academy and enterprise) made joint efforts to start a pilot project at the Tayrona National Natural Park using two coral nursery designs: line (Ross 2008) and floating (Shafir & Rinkevich 2008) to assess coral survivorship and growth, as well as associated costs for a larger project on coral culture and future restoration. *Acropora cervicornis* and *A. palmata* fragments were cultured for 18 months in both nurseries.

Obtained results show no significant differences between nurseries survivorship and growth in the first 7 months. After that period, growth rates of the fragments of the floating nurseries decreased, possibly due to the size of the substrates used to grow them. Additionally, a severe bleaching event occurred in the region between August and December 2010, which resulted in lower fragment growth rates; however mortality was low (< 5%) in both nurseries compared to natural populations (20-90%). Although associated costs were higher for the floating nursery the advantages of growing several coral species, beside acroporids, resulted in the deployment of a new nursery where both, line and floating, designs were combined to culture up to 10000 fragments for future restoration of Tayrona's shallow water reefs.

20A Restoration of coral reefs
Wednesday 11 July, 1040, Sebel Bluewater

Coral reef restoration based on sexual coral reproduction

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The importance of coral reefs calls for protection and restoration. Most current restoration methods for reef building corals rely on clonal propagation. However, sexual reproduction, which may enhance genetic diversity is indispensable for future adaptations and will be crucial in times of climate change. As part of the FORCE project (Future Reefs in a Changing Environment), we used *Acropora palmata* to evaluate the potential of sexual reproduction as a tool for restoration. Settlers of *A. palmata*, which were derived from gametes collected during the mass spawning event in August 2011, were raised in a flow-through coral nursery and were used for a reintroduction experiment. Corals at different ages were transplanted into reef sites to evaluate the reintroduction success. Survival and growth of these settlers were compared to natural recruitment to evaluate whether reintroduced sexual recruits can accelerate reef regeneration. High *ex situ* fertilization (85,6±11,3%) and settlement (16,7±3,8%) rates were achieved and subsequently, 1,500 primary polyps were transplanted at two reefs in August 2011. An estimated 32,800 sexual recruits remained in the coral nursery for outplanting in October 2011 and February 2012. The study will provide data on the optimal timing of reintroduction and show if early transplantation of sexual recruits can result in successful restoration. First results from coral larvae culture and settlement indicate that the novel restoration techniques can be promising for future large-scale applications. In particular, endangered coral species whose genetic diversity is declining can benefit from the novel restoration strategy.

20A Restoration of coral reefs
Wednesday 11 July, 1015, Sebel Bluewater

Propagation and protection of *Acropora cervicornis* in Caribbean coral nurseries

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With staggering declines of *Acropora* in the Caribbean, it is imperative that management and conservation efforts include targeted restoration activities that maximize production of *Acropora* tissue while exerting minimal impacts on remaining wild populations. *In situ* coral nurseries provide a productive, sustainable source of coral colonies for use in restoration activities, and contribute to the preservation and enhancement of local genotypic diversity. Growth of nursery-reared *Acropora cervicornis* fragments in Biscayne National Park, Florida, USA, has significantly increased the stock available for restoration, as well as provided important data on the growth and survivorship of this species. Key findings include: 1) donor colonies exhibited limited mortality and demonstrated pruning vigor that resulted in a net gain in coral productivity, 2) fragment productivity (growth normalized by initial size) increased significantly after branch formation, and 3) branching can be induced by 'scoring' fragments (making small skeletal lesions), prompting the formation of new apical polyps. Additionally, coral nurseries strategically placed can also provide refuge from environmental extremes. In 2010, coral nurseries in Florida served as repositories for genetic material that would have been otherwise lost to extensive *Acropora* mortality at donor reefs during a cold-water anomaly. While coral propagation efforts will always pale in comparison with the scale of natural recovery through sexual recruitment, targeted propagation and restoration efforts can still have a considerable impact on the localized recovery of depleted coral reefs and provide insight in the population dynamics of key coral taxa that will ultimately contribute to better management of these threatened resources.

20A Restoration of coral reefs
Wednesday 11 July, 1430, Sebel Bluewater

Evaluating sexual versus asexual propagation methods for breeding sea anemones that host anemonefish

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Ten species of sea anemone provide essential habitat for 26 species of ectosymbiotic anemonefish. Due to the fascinating nature of this relationship, these anemones are highly sought after in the marine aquarium trade. The lack of information on propagation methods has meant that individuals are sourced from the wild, causing localised depletions in some areas of the Indo-Pacific. These anemones also form a relationship with endosymbiotic zooxanthellae, and bleaching events can result in further depletions. The development of appropriate culture techniques for these anemones could therefore support biodiversity conservation, by either reducing collecting pressures on wild populations or by providing animals that can be used to restock depleted reefs. *Entacmaea quadricolor* (Rüppell and Leuckart 1828) is the most common and geographically widespread host actinian. This species can reproduce sexually via broadcast spawning and asexually via longitudinal fission. Characteristics that appear favourable for captive breeding through sexual reproduction include having predictable annual spawning seasons, releasing large numbers of broadcast spawned gametes that fertilise readily in aquaria, and producing larvae that have a relatively short planktonic period and settle onto a variety of substrata. Alternatively, artificial fragmentation could produce individuals throughout the year. This paper will present an evaluation of using sexual versus asexual reproductive strategies to breed this species in captivity, whilst also outlining the role that captive breeding could have for the conservation and management of these anemones and their resident fish.

20A Restoration of coral reefs
Wednesday 11 July, 1545, Sebel Bluewater

Success stories: coral transplantation in Indonesia

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Coral transplantation activities, aka coral fragmentation, have been carried out by Indonesian researchers, national park authorities, and conservation practitioners in order to facilitate reef rehabilitation programs, as well as to produce colonies for the ornamental coral trade. The ornamental coral trade has existed in Indonesia for more than 30 years, for export to the USA, Europe, Hong Kong, and Singapore, among others. Over 1.5 million coral pieces are exported per year from Indonesia, which is higher than the Philippines, Fiji, and countries in the Caribbean. Indonesia follows the rules applied in legal trade of corals established by CITES, with the Indonesian Ministry of Forestry acting as the management authority following approval of the established quota by the Indonesian Institute of Sciences. Research aimed at doubling coral transplants has been successfully conducted by the Faculty of Fisheries and Marine Sciences, Bogor Agricultural University in the Kepulauan Seribu since 1998, which is now applied by the government as a technical guide for coral transplantation in Indonesia. Nowadays, collection of natural coral colonies is banned by local government at several provinces and coral exporters are urged to buy colonies from coral farmers who mostly utilize coral transplantation methods.

20A Restoration of coral reefs
Wednesday 11 July, 1735, Sebel Bluewater

Potential impact of fish predation on transplanted cultured corals in Thailand

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The eightband butterflyfish *Chaetodon octofasciatus*, java rabbitfish *Siganus javus*, bengal sergeant *Abudefduf bengalensis*, and the pastle-green wrasse *Halichoeres chloropterus* are the dominant fish species in reefs. Dependant on the species, they graze and prey on algae, invertebrates, and coral tissues. In this study, we investigated the potential impact of grazing of fish on transplanted cultured corals in Thailand. In addition, the sizes of fish and the sizes of bite marks were also monitored and recorded. The results showed that all fish preyed on corals. There was no correlation between the sizes of fish and the sizes of bite marks of *S. javus*, *A. bengalensis*, and *H. chloropterus*. However, *C. octofasciatus* show the trend of a positive correlation between sizes of bite marks and sizes of fish. The mean sizes of bite marks of *C. octofasciatus*, *S. javus*, *A. bengalensis*, and *H. chloropterus* were 0.34, 0.36, 0.70, and 0.29 cm^2, respectively. From both field and laboratory experiments in this study, the feeding of *S. javus* could have a high potential impact on juvenile corals and transplanted cultured corals.

20A Restoration of coral reefs
P219

Chemically-enhanced settlement of acroporid coral larvae on artificial surfaces

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The recovery of damaged coral reef systems may be facilitated by reseeding these sites with settled juvenile corals or by enhancing natural settlement of coral larvae *in situ* to replenish adult stocks. This strategy requires strong settlement cues that can be reproducibly deployed on artificial surfaces to induce high rates of larval attachment and metamorphosis. We have extracted highly inductive chemical cues for coral larval settlement from a variety of natural sources. These cues were purified and immobilized on different substrate types (terracotta, PVC, and concrete). One batch of these substrates was submerged in tanks containing larvae of the corals *Acropora millepora* and *A. tenuis*. A second batch of substrates was deployed on the reef prior the annual coral spawning events to compare settlement rates obtained under laboratory conditions with natural recruitment rates measured *in situ*. High settlement rates of both *Acropora* spp. were observed on substrates maintained under laboratory conditions. In contrast, substrates deployed on the reef revealed low numbers of coral recruits, possibly due to early predation on easily accessible coral juveniles. This study provides proof-of-concept that chemical cues for coral larval settlement can be immobilized on artificial substrates while maintaining their activity. This technology allows us to further investigate the immobilization of other bioactive chemistries to control bacterial and/or algal overgrowth and improve post-settlement survival of juveniles with anti-predatory measures (e.g. caging).

20A Restoration of coral reefs
Wednesday 11 July, 1130, Sebel Bluewater

Comparison of assemblages on rocky shores and seawalls in Singapore

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Rapid urbanization and land reclamation has modified much of Singapore's natural rocky shores and coral reefs, replacing them with granite riprap seawalls to protect the coast from erosion. Research elsewhere has shown that artificial reinforcements share several superficial characteristics to rocky shores, though exactly how close the resemblance is varies from study to study. However, there has been no research of this kind in Singapore conducted heretofore, despite the ubiquity of seawalls in this island nation. In fact, there have been no such studies conducted in the tropics. To fill this knowledge gap, three Singaporean sites will be surveyed over the period of a year and comparisons of the community assemblages, diversities and abundances made between rocky shores and seawalls adjacent to coral reefs. Both spatial (among sites) and temporal variation (among months/quarters) differences will be investigated. Stable isotope analyses will also be performed to determine the diet composition and trophic level of several common species to help reveal community structure and food web differences. By understanding the biology of these natural and artificial environments better, more can be done to mitigate the loss or change of biodiversity during future coastal developments.

20A Restoration of coral reefs
P220

Rearing sexually propagated massive corals for reef rehabilitation: feasibility and cost effectiveness

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Rehabilitation efforts to facilitate recovery of coral reefs have become an increasingly popular management tool; however the science underpinning restoration is still in its infancy. One of the techniques involves propagating corals for transplantation to degraded reefs using sexual reproduction. As opposed to asexual fragmentation, this technique enhances genetic variability and harbours the potential for large-scale application. To date, there have been several studies documenting the outcomes of these efforts, but most have tended to use fast-growing coral taxa such as *Acropora* and realistic cost assessments are rarely included. In this study, gravid colonies of *Montastraea colemani* and *Favites halicora* were spawned *ex situ* in Bolinao, Northwestern Philippines, in May 2009. The coral larvae were settled on purpose-built cement substrates (called coral plugins) and reared *ex situ* for one year. A total of 1213 *M. colemani* and *F. halicora* juveniles were transferred to an *in situ* nursery, adjacent to the natural reef. Outplanting of juvenile corals was conducted in March and June 2011 to determine the survivorship and growth rates in the field. The economic feasibility of this technique was assessed by taking fixed and consumable costs, man-hours and projected survivorship for consideration at three stages: (1) *ex situ*

spawning and larval rearing (2) *ex situ* and *in situ* nursery maintenance and (3) transplantation. While initial cost estimates suggested that this technique is expensive, this is the first report of sexually rearing massive corals from eggs to transplantable juveniles and highlights its technical feasibility as a reef rehabilitation tool.

20A Restoration of coral reefs
Wednesday 11 July, 0945, Sebel Bluewater

Advancing culture technologies for propagation of coral species for restoration

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Various technologies are presented and reviewed for the cultivation of hard corals for reef restoration. Coral cultivation using asexual reproduction with fragmentation has been accomplished for over six years for over a dozen species of hard corals using indoor, outdoor and recently *in situ* cultivation methods. Land-based culture methods used 2.5 cm fragments that were attached to concrete bases in indoor facilities with artificial light and outdoor facilities using natural light conditions using salt water from a ground well. Field planting in near-shore and off-shore nurseries are compared with seasonal plantings and for growth for four field planted hard coral species. Newer methods of micro-fragmentation using just one or a few polyps to produce a new colony will also be presented. Cultivation using sexual reproduction methods was also accomplished for both brooding corals with *P. astreoides* and for broadcast spawning with *M. faveolata*. Comparisons of the numbers of settled larvae and survival for planting are reviewed. Effectiveness of sexually produced recruits are compared. A unique method of transferring a single recruited polyp and micro-fragmenting individual settled colonies onto separate bases are presented. This land-based and indoor controlled conditions, allows for higher survival of settled recruits and an improved method of coral cultivation for restoration plantings. The combination of controlled land-based culture conditions for the first few critical months after settlement and then the in-field nursery transplanting provides an effective way to produce large numbers of cultured coral for reef restoration.

20A Restoration of coral reefs
Wednesday 11 July, 1200, Sebel Bluewater

Assessment of growth and survival of cultured juvenile corals, *Acropora* spp. after transplantation into the reefs

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Coral reefs in Thailand are hotspots for the tourism and fisheries industries, and therefore are of paramount importance for the economy of Thailand. However, Thai reefs have been steady degraded due to both anthropogenic activities and natural disturbances. One method recently introduced for coral restoration in Thailand is the coral culture technique using sexual reproduction. In this study, we investigated the growth and survival of the cultured juvenile corals, *Acropora* spp. after transplantation onto the reefs. Cultured juvenile corals were transferred onto the reefs at different ages ranging from 6 months to 3 years old. The results showed that the survival rates of transplanted juvenile corals were high if transplanted corals were at least 1 year old. Observations indicated that when juvenile corals were in the hatchery, colonies grew by expanding in width. However, after transplantation into the sea, the colony growth resulted in expansions in height. Overall, the survival rates after transplantation were more than 50% depending on the sizes of transplanted juvenile corals. Fouling organisms and fish predators were the main factors influencing the growth and survival of transplanted juvenile corals in Thai water.

20A Restoration of coral reefs
P221

Coral-reef restoration by transplantation of cultured juveniles to artificial reefs

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Coral reefs enable the maintenance of rich fishing grounds through high primary productivity and through their complex structure, which provides habitats and refuge for the fishery resources. Recently, coral reefs have functionally collapsed because of global and local disturbances. Such degradation of the reefs may seriously influence the tropical and subtropical fishery resources of our country. For developing useful and efficient techniques and technology for coral reef restoration, we commenced a project at Okinotorishima, the southernmost island of Japan, in 2006. In this project, 75,500 juvenile

corals at the age of approximately 1 year, which were mass cultured from eggs, were transplanted to the reef in 2008 and 2009. Among the coral colonies transplanted in 2008, colonies protected with mesh cages steadily increased their coverage nearly 4-fold in approximately 2 years. This study proves that predation pressure is one of the factors leading to coral growth constraints, and that it can be avoided by using artificial techniques. Moreover, we have developed artificial reefs for coral reef rehabilitation since 2009. The artificial reefs are expected to provide suitable substrates for the transplanted juvenile corals in devastated reefs, and to reduce the negative impact of anthropogenic activities, by using physical functions of the artificial structure. We discuss the effectiveness and validity of the transplantation methods and the artificial reefs, based on the results of the long-term monitoring of transplanted juveniles. This study was carried out as part of a coral propagation project by Fisheries Agency, Japan.

20A Restoration of coral reefs
P222

Review of reef restoration activities in the Caribbean

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A study was conducted to gather the collective knowledge, opinions, and lessons learned of practitioners with regards to the field of coral reef restoration, paying particular attention to projects focusing on the threatened genus *Acropora* in the Caribbean, Western Atlantic, and the Gulf of Mexico. A review of coral reef restoration activities was conducted throughout the region, and an online survey was conducted to identify the most effective reef restoration methods, as well as the major advantages and disadvantages of conducting reef restoration activities. Education and increased public awareness were ranked as the highest potential benefits of reef restoration, while high financial costs, the small footprint of restoration activities, and potential damage to wild populations were identified as major concerns for practitioners. Finally, low-tech methods such as coral gardening and fragment stabilization were ranked as the most effective among practitioners. Results of this study not only highlight the benefits and concerns of coral reef restoration, but also its potential role as a complementary management tool for coral reef conservation in the region.

20A Restoration of coral reefs
Wednesday 11 July, 1730, Sebel Bluewater

Theme 21. Water quality: impacts & management

21A. Watershed management & reef pollution

Spatial-temporal variation in exposure of marine ecosystems to land-based threats

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Increased loads of sediment and nutrients from land-based human activities are a major threat to coral reefs in the Great Barrier Reef (GBR). Identifying the sources of these pollutants, their distribution and the scale of influence on marine areas is required to effectively assess the ecological impacts of degraded water quality. Understanding of the risk to GBR ecosystems from pollutants provides better information for mitigation. Modelled and measured load data was used to calculate long-term and annual loads (2007-2011) of dissolved inorganic nitrogen (DIN) and total suspended sediments (TSS), as well as the variation in proportional contribution of DIN/TSS from each major river across the study region. We applied a combination of algorithms to MODIS imagery to map the extent and water composition of surface flood plumes. For areas where plumes could not be mapped due to atmospheric conditions (e.g. cloud cover), we used a technique that combines radiometric enhancement and unsupervised classification of true colour imagery to fill in the blanks. Daily surface plume maps were then overlaid to calculate the frequency of exposure to plumes/pixel during each wet season. Using GIS routines we produced a pollutants surface, which combines mapped plumes and loads to represent the dispersal of pollutants. Finally, we combined the pollutant surface with plume frequency to create a surface that shows the relative exposure of marine areas to DIN and TSS; this surface incorporates a confidence index based on data availability/pixel. We compare long-term and annual exposure, and discuss implications for catchment management.

21A Watershed management & reef pollution
Monday 9 July, 1500, MR3

Comparison of heavy metal accumulation in Scleractinian corals from Almirante Bay, Panama

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Chemical pollutants are composed of various persistent heavy metals that pose a variety of deleterious effects on marine biota, including corals. Little is known with regards to the effects of heavy metals on adult corals, or the concentrations these animals are able to tolerate with acute and chronic exposure in their natural habitats. Furthermore, few studies have compared cellular response mechanisms between corals exposed to environments influenced by direct sources of pollution. For these reasons, two *in situ* experiments were conducted within Almirante Bay, Panama, Central America, to examine and compare the accumulation patterns of cadmium, copper, zinc and mercury in the tissue of two scleractinian coral species, *Porites furcata* and *Agaricia tenuifolia*. Both species exhibited histological evidence of stress response to heavy metal exposure including swelling of mucocyte cells, tissue distension and degradation. Findings revealed different patterns of heavy metal uptake and release between species over time. *Porites furcata* contained higher metal concentrations suggesting that it had a higher potential for heavy metal uptake and storage. *Agaricia tenuifolia* heavy metal tissue concentrations were significantly lower than in *P. furcata* and often similar to control corals, which indicates either lower uptake or higher excretion potential. Variations in metal uptake and release across study sites within the Bay demonstrated that heavy metal fluxes through corals may be controlled by hydrology and heavy metal source. These results clearly demonstrate inter-species differences in accumulation and regulation of heavy metals in coral tissues.

21A Watershed management & reef pollution
P223

Improving sewage treatment in a National Park: did it matter?

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To comply with U.S. Environmental Protection Agency regulations, twenty large-capacity cesspools were replaced by septic tanks and leach fields in 2007 at Kalaupapa National Historical Park in Hawai`i. A BACI sampling design was used to evaluate the efficacy of the sewage treatment upgrade on nearshore water quality. Three different algal species were analyzed for stable nitrogen isotope ($\delta^{15}N$) values at three depths within a grid at both the impact and control site. Sampling was conducted four times (twice, pre and post

upgrade) over a five year span beginning in 2006. At the onset of the study, $\delta^{15}N$ values were not significantly different among species (mean values: *Lobophora variegata*: 1.84‰, *Sargassum obtusifolium*: 1.50‰, *Stypopodium flabelliforme*: 1.27‰), depths (shallow: 1.64‰, medium: 1.44‰, deep: 1.38‰), or sites (Impact: 1.50‰, Control: 1.43‰), indicating normal seawater nutrient levels with low sewage input. Over time, the response varied by species with *S. obtusifolium* $\delta^{15}N$ values increasing significantly at both sites, but still within normal seawater values (Impact: 1.80‰, Control: 2.18 ‰). In comparison, $\delta^{15}N$ values for the other two species indicated no changes in nutrient levels at either site. During the study period, percent coral cover did not vary significantly at permanent monitoring stations in close proximity to the sampling areas. Increased park visitation in the future may ultimately justify the $5.2 million expense, but the present study suggests that the sewage treatment upgrade did not improve nearshore water quality and might have been unnecessary.

21A Watershed management & reef pollution
Monday 9 July, 1645, MR3

Mary River flooding affects coral reefs of Hervey Bay, Australia.

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Although considered marginal, the coral reefs of Hervey Bay, Queensland Australia are a relatively healthy and unusual example of subtropical, turbid-zone coral reefs. They represent an important link between the more tropical reefs of the north, including the Great Barrier Reef, and the sub-tropical regions to the south. In December 2010 and January 2011, the Mary River in southern Queensland experienced one of the largest flood events on record. The flood plume from the Mary River extended into Wide Bay and travelled north. The waters adjacent to Hervey Bay were brown with silt for several months. Through the use of photo transects and point intercept analysis, the per cent cover of hard and soft corals were measured prior to and just after the flooding event. Sites were located from 10km to 50km away from the mouth of the Mary River. Hard corals showed variable response to the floods, but there were clear reductions in per cent cover both near to and distant from the river mouth. Soft corals generally showed a decrease in per cent cover, with severe reduction in per cent cover in a number of locations. In one location, the impact of the floods was severe including a 70% reduction in hard coral and a 99% reduction in soft coral. At this location, the larger hard coral colonies that died were probably hundreds of years old and would have survived numerous large flood events. Results of further analyses of these dead corals will be presented.

21A Watershed management & reef pollution
Monday 9 July, 1530, MR3

Managing coral reefs from ridge to reef

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It is now well accepted that many major coral reef ecosystem stressors originate from land based sources and the health of many U.S. coral reef ecosystems depends on effective management of land-based activities in adjacent coastal and upland regions. Within the United States and its jurisdictions, there are numerous locations where coral reef ecosystems are highly impacted by watershed alteration, run-off, and coastal development. Impacts of these land-based sources of pollution cross multiple jurisdictional boundaries with the authority and responsibility to address them falling to a multitude of governmental and jurisdictional levels. It is therefore necessary to build a management framework that facilitates enhanced coordination across agencies and organizations with authority and expertise to address land-based sources of pollution and land-based activities. Strategic and targeted partnership is essential to most effectively address this threat. This session will explore how NOAA's Coral Reef Conservation Program (CRCP) and the Restoration Center are partnering with other federal agencies and working collaboratively with jurisdictional partners to address the impact of land-based sources of pollution. The CRCP has recently gone through a strategic planning process and identified 5-year objectives for land-based sources of pollution. The CRCP will share the process for developing these objectives and the vision for collaborative and strategic action in priority coral reef watersheds. We will then explore two innovative local initiatives in Guánica, Puerto Rico and West Maui, Hawaii that are making demonstrable progress in decreasing the sources of and impacts from land-based sources of pollution on coral reef ecosystems.

21A Watershed management & reef pollution
Monday 9 July, 1015, MR3

Identification of plume water types in the Great Barrier Reef

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Integration of innovative spatial analysis techniques with remote sensing data provides detailed information on the movement, extent and content of surface plumes in the Great Barrier Reef. Daily MODIS imagery for the GBR were extracted for the periods between January and May from 2002 to 2011. A classification procedure was applied to these images using a set of thresholds applied to the Level-2 ocean colour products. Three water types were identified: (i) a primary water type characterised by high TSS values within the core of low salinity plume water; (ii) a secondary water type characterised by high phytoplankton production as measured by elevated chlorophyll-a (chl-a) and high values of coloured dissolved and detrital matter (CDOM+D) and (iii) a tertiary water type characterised by elevated CDOM+D. *In situ* water quality data collected within flood plumes over the same period were used to validate the water typology and provided further information on the large scale mapping of the water quality characteristics specific to the movement of GBR flood plumes. These mapping outputs allow a preliminary assessment of the number of days in which key GBR ecosystems are exposed to those identified water types. A spatial and temporal matrix of water quality conditions, including nutrients, TSS, chl-a, salinity and temperature, which have influenced inshore ecosystems is presented for seagrass bed and inshore coral ecosystems and integrated into the risk mapping of GBR ecosystems.

21A Watershed management & reef pollution
P224

Effect of cryopreservation on the quality of *Pinctada margaritifera* spermatozoa

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Spermatozoa cryopreservation is a useful tool for genetic improvement and has been applied to several bivalve mollusc species. This technology would allow preservation of the gametes of individuals selected for their high growth capacity or the quality of their pearl, and thus provide significant benefits to the cultured black pearl industry. Sperm freezing requires the control of different steps: preparation of breeders, sperm collection, evaluation of sperm quality and the freezing process itself. The aim of this work is to determine the influence of cryopreservation on spermatozoa quality of *Pinctada margaritifera*. In order to explore the sperm quality, different criteria need to be measured such as the ultrastructure, concentration, motility and metabolic activity of the sperm. Sperm was manually collected after natural shedding from the gonopore. After appropriate dilution in seawater or activating medium, spermatozoa motility was estimated using light microscopy. Respiration rates were determined with a Clark electrode, ATP content of the whole sperm was evaluated using a bioluminescence assay and creatin kinase activity was estimated using a colorimetric assay. Ultrathin sections were prepared for TEM examination. Concerning the freezing process: sperm was diluted in a cryoprotectant then drawn into semen straws. After equilibration at room temperature then in liquid nitrogen steam, the straws were immersed in the liquid nitrogen for at least 2 hours and finally thawed at room temperature. Our results demonstrated that alkaline medium allows sperm reactivation. Thereby, spermatozoa are able to restore a low motility and a weak metabolic activity after cryopreservation.

21A Watershed management & reef pollution
P225

Fast detection of nutrient limitation in macroalgae

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Rapid determination of which nutrients limit the growth of macroalgae can be of considerable importance for understanding the trophic status of coral reef ecosystems. Detection of nutrient limitation using the NIFT technique (Nutrient-Induced Fluorescence Transient) has been widely applied to pelagic phytoplankton. We developed an experimental set-up by which this technique can be extended to benthic macro algae on coral reefs. As a first test, a macroalga (*Ulva lactuca*) was cultured in the laboratory and provided with all nutrients except nitrogen or phosphorus. Addition of the limiting nutrient resulted in a characteristic change in the fluorescence signal using a Pulse Amplitude Modulated (PAM) fluorometer. Subsequently, we applied the NIFT technique to the macroalga *Lobophora variegata* collected from coral reefs at Curaçao, and

found that phosphate rather than nitrate or ammonium was the limiting nutrient. Compared to other methods assessing the limiting nutrient in macro algae, the NIFT technique is a very easy and fast method (approximately 1 h per sample). While we worked on coral reefs, we foresee a wider application of this method to benthic algae of other marine and freshwater ecosystems.

21A Watershed management & reef pollution
Monday 9 July, 1730, MR3

The impacts of extreme weather conditions on the inshore GBR

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There has been a well-recognized link between declining water quality and the ecological health of coastal ecosystems. A strong element of changing environmental condition throughout the GBR is the pulsed or intermittent nature of terrestrial inputs into marine ecosystems, particularly close to the coast. Delivery of potentially detrimental terrestrial inputs of freshwater, sediments, nutrients and toxicants typically via flood plumes, will be exacerbated under modelled climate change scenarios and presents an ongoing risk to the resilience and survival of inshore GBR ecosystems. This talk will present an assessment of the impact of the extreme weather which had resulted in heavy flooding and large scale disturbances such as the Category 5 cyclone which crossed the Queensland coast on the 2nd February. Data collected within the Marine Monitoring program will be presented, including the spatial and temporal extent of the altered water quality conditions as measured by *in situ* sampling and satellite imagery. This work will be presented with supporting data from other key indicators including seagrass communities and inshore coral reef systems documenting the full scale of the impact of the extreme weather conditions on the GBR ecosystem. The consequence of this long wet season has had profound impacts on the people living and working within the Queensland coastal area, but may also be the driver of large scale reported decline in the many inshore seagrass systems and coral reefs, with concerns for the recovery potential of these impacted ecosystems.

21A Watershed management & reef pollution
Monday 9 July, 1000, MR3

Restoration of a threatened watershed through community volunteerism

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The Guam Environmental Alliance (GEA) is a newly formed non-governmental organization that seeks to promote environmental causes through community action. GEA started the Masso Watershed Restoration project in October 2010, in conjunction with Marianas Resource Conservation and Development. The Masso watershed is found in southern Guam, covers approximately 500 acres (2 km^2), and leads to Piti Bay, one of Guam's Marine Protected Areas. Threats to the Masso watershed include erosion and sedimentation exacerbated by fires (arson), off-roading vehicles, poorly planned construction projects, and invasive ungulates. The restoration project focused on planting native trees, along with an introduced but important nitrogen-fixing species (*Acacia auriculiformis*) throughout the watershed area. Several factors proved fundamental in garnering support for the project: (1) focusing on the connection between the watershed and the health of coral reefs (2) involvement from community organizations with a commitment to long-term stewardship of the area, and (3) education in the forms of outreach, involvement with school and youth groups, and interpretive signs throughout the area being rehabilitated. Volunteers planted over 3,000 seedlings during three different planting events. The area restored is easily accessible to the local community; it is comprised of several hiking trails and a reservoir that will be turned into a recreational fishing area. GEA's future work will focus on linking watershed restoration to water quality and reef health.

21A Watershed management & reef pollution
P226

Management of coral reef resources in Guam's National Park

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War in the Pacific National Historical Park, Guam

The greatest area of War in the Pacific National Historical Park in Guam consists of coral reefs containing the highest marine biodiversity within the U.S National Park System. These reefs have been directly damaged by intensive military landings and land based sources of water pollution. A well designed long term continuous monitoring program of the National Park Service has been sampling water quality

and related biological characteristics of the Park watershed streams and receiving reef waters for over five years. It is supplemented by other cooperative monitoring efforts by government agencies and university researchers. Additional studies of the Park watersheds and reefs from 1974 onward include baseline and related comparable data on water quality; reef resources; oceanography; multiple permitted uses, including fishing and recreational diving, and their impacts; and watershed vegetation, soils, slopes, land use, erosion factors and management plans. Resources are managed through a cooperative network of regulatory agencies. A portion of the Park reef area is managed as a marine protected area. Cases of pollution management are presented.

21A Watershed management & reef pollution
Monday 9 July, 1245, MR3

Factors affecting land-based sedimentation in coastal bays, US Virgin Islands

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In the US Virgin Islands, land-based sources of pollution (LBSP) including sediment and storm-water runoff are one of the primary causes of coral reef degradation. Previous research in the USVI has demonstrated that the building of roads and watershed development has increased the land-based (terrigenous) sedimentation accumulation in the coastal bays with coral reefs. From 2008-2010, our research team and community partners have conducted marine sedimentation (using sediment traps) and water quality monitoring directly below developed watersheds (in Coral Bay) and below undeveloped watersheds for comparison. These data suggest that total and terrigenous sediment trap accumulation rates on some reefs below developed watersheds were significantly higher than below undeveloped watersheds, and that chronically high sedimentation on some reefs were consistent with rates shown elsewhere to have caused severe stress to corals. There were also marked differences in sedimentation patterns between shore, mangrove, bay and reef environments. The recent completion (Spring, 2011) of watershed sediment control projects funded by ARRA/NOAA above our study sites in Coral Bay provides an opportunity to evaluate whether these mitigation projects have impacted the quantity, quality (type), and spatial variability of sedimentation in the short term. Temporal comparisons of our pre-mitigation (baseline) (2008-2011) and post- mitigation data (2011-12), complemented by spatial comparisons between areas below developed, undeveloped and mitigated watersheds may provide data to inform the development of Best Management Practices (BMP) applicable to other tropical islands.

21A Watershed management & reef pollution
Monday 9 July, 1215, MR3

Water quality guidelines for maintaining a healthy Great Barrier Reef

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In order for marine ecosystems to be healthy they need good quality water. This is especially important in light of the challenges climate change poses for the Great Barrier Reef. In 2009 the Great Barrier Reef Marine Park Authority published water quality guidelines that apply information on the effects of different concentrations of sediment, nutrient and pesticides (primarily herbicides) to identify the levels for maintaining the health of the Reef. The Great Barrier Reef Marine Park Authority's monitoring program measures the concentrations of pollutants in the water, compares them to the guidelines and if they are not met we look to see what more can be done upstream to bring the concentrations down. At the same time research is underway to improve our confidence in the guidelines, to ensure we are protecting the health of the entire marine ecosystem. Monitoring results show that over the past 10-15 years there are times when, and for coastal waters in particular, concentrations are over those considered best for maintaining the health and resilience of the Great Barrier Reef. As actions are taken that reduce losses of pollutants to catchment waters, the water quality of the marine system is expected to improve, although lag times are not well understood. We will continue to track these improvements over the long term to assess progress to the Government's 2020 target.

21A Watershed management & reef pollution
Monday 9 July, 1715, MR3

Waste disposal on small island nations: the Bermuda seafill

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Bermuda is a densely populated coral atoll located in the mid-Atlantic. As with many other densely populated small island nations, waste disposal is a major problem. In the absence of

suitable landfill space, bulk waste (including used cars, fridges etc) and municipal solid waste incinerator ash is dumped in the sea, at a foreshore reclamation site effectively a marine landfill - or seafill. Aerial images show the seafill has grown to encompass an area of 25 acres over the last 35 years. Such disposal practices are not uncommon on coral atolls. As part of a process for establishing baselines for management purposes, extensive surveys were conducted of sediment contaminant concentration along transects radiating out from the seafill and compared to multiple other locations in Bermuda including offshore sites and sites influenced by light industry. Analyses of seawater leaching from the seafill indicated some metal concentrations routinely exceeded water quality guidelines, and there was a 'halo' of sediment contamination by multiple contaminant classes including metals, polycyclic aromatic hydrocarbons, petroleum hydrocarbons, dioxins and furans, polychlorinated biphenyls and an organochlorine pesticide. When examined against biological effects-based sediment quality guidelines (SQGs), numerous sediment samples around the seafill, and in other hot-spots in Bermuda, exceeded the low-range values (where biological effects become possible), and for Hg and Zn and Cu the mid-range value (where they become probable). A few metres away from the edge of the seafill lies a small coral patch reef - proposed here as the most contaminated coral reef in the world.

21A Watershed management & reef pollution
Monday 9 July, 1630, MR3

Environmental gradients from coral cores on the Great Barrier Reef.

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Coral cores were collected along an environmental gradient associated with river discharge of terrestrial material in the Whitsunday Island Group for trace element and stable isotope analysis. The aim of the study was to examine if this gradient could be detected in trace chemicals in coral records and, if so, whether the chemical composition has changed over time correlated with changing land use in the adjacent Proserpine and O'Connell River catchments. We found that the Ba/Ca ratio, a proxy of sediment input, was the only indicator of change in the gradient shortly after European settlement (ca. 1860). The Mn/Ca ratio responded to local-scale changes in the islands related to tourism infrastructure, while the Y/Ca ratio was the only coral proxy to respond to the environmental gradient, with concentrations progressively decreasing from the river mouth. $\delta^{15}N$ in the long coral record from Cid Harbour Island showed no apparent trend over time suggesting that nutrients may be diluted or transformed before reaching this site, or alternatively that $\delta^{15}N$ is a poor indicator of fertiliser runoff in this region. The findings from this study highlight the importance of site selection when using coral records to detect regional-scale environmental signals. In particular, sites which have a poor correlation between coral luminescence and river discharge, have complex currents associated in our case, with multiple islands and strong tides and island wakes, and possibly have both near field (adjacent island streams and waste discharges) and far field (mainland rivers) influences of chemical runoff should be avoided.

21A Watershed management & reef pollution
Monday 9 July, 1545, MR3

Phosphorus records in corals provide archives of terrestrial runoff

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Background: Worldwide increased catchment runoff (e.g. nutrients and sediment) is having detrimental effects on coral reefs. However, the limited availability of water-quality time-series has hindered our understanding of nutrient dynamics and subsequent reef development. In this study we used: 1) unique multi-year *in situ* phosphorus (P) time-series records from the Tully river; and 2) long-term catchment fertiliser-P records to validate the proxy development of skeletal P records (P/Ca) in coral cores. We then assessed the relationship between P and coral calcification. Methods: P records in coral cores from near-shore Dunk Island were examined using X-ray mapping by electron-probe microanalysis (EPMA) and laser ablation mass spectrometry (LA-ICP-MS). Results were compared with unique historical data sets of fertiliser-P and river water quality. Coral calcification was then compared with contemporaneous P records. Results: Findings demonstrate that P is incorporated down-core throughout the aragonite coral skeleton, and that riverine particulate P and fertiliser-P records are positively correlated with multi-

decadal P records in coral cores. We did not observe any significant change in coral calcification over the past three decades. Conclusions: In conclusion, our contemporaneous LA-ICP-MS and EPMA findings support the continued development of this promising seawater P archive. These findings also suggest that this approach has the potential to provide quantitative measures of long-term changes in P fluxes. Interestingly, increased sediment and nutrient inputs do not appear to be negatively impacting calcification of our *Porites* colonies at this site suggesting that sediment tolerant species may be compensating with other growth mechanisms.

21A Watershed management & reef pollution
Monday 9 July, 1515, MR3

Detecting reef water quality using stable carbon and nitrogen isotopes

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Water quality and overall ecosystem productivity can be negatively impacted by a variety of ocean- and land-based sources of pollution such as hydrocarbons, agriculture, development, and sewage. Stable carbon and nitrogen isotopes may be a useful tool for tracking relative changes in water quality on coral reefs. Two gorgonians, the purple sea fan (*Gorgonia ventalina*) and the sea rod (*Pseudoplexaura porosa*) from Bermuda were analyzed for stable carbon and nitrogen isotopes. *Gorgonia ventalina* was collected from four nearshore and five offshore sites for one-time analyses, and to determine a range of values around Bermuda. *Pseudoplexaura porosa* contains annual rings and was collected from two locations to assess a change in values throughout the lifespan of each colony. Nitrogen was more enriched in ^{15}N in colonies from nearshore compared to those from offshore sites, most likely reflecting higher levels of land-based nitrogen pollution in the seawater closer to the coastline. There was a slight west to east trend with carbon becoming progressively more depleted in colonies from more eastern sites. In combination, the isotopic signatures were site specific, even within the relatively small area of Bermuda, and may be useful for monitoring relative changes in water quality at local scales.

21A Watershed management & reef pollution
Monday 9 July, 1700, MR3

Controls on residence time of terrestrial sediment on coral reefs

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Oceanographic measurements and sediment samples were collected in Hanalei Bay, Kauai, Hawaii, USA, from 2005-2007. These data were integrated with a physics-based numerical model to understand the delivery, residence time, and advection of fluvial sediment out of a coral reef-lined embayment. A flood during the summer caused high turbidity in the bay, but the plume dissipated within a few days. Waves and currents, and the resulting seabed shear stresses, were more energetic in the western and southern portions of the bay that are more exposed to trade-wind and far-field storm waves, resulting in little to no fine-grained terrestrial sediment accumulation. Seabed shear stresses along the sheltered eastern part of the bay in the vicinity of the river mouth, however, were below the threshold for erosion of fine-grained sediment more than 90 percent of the study period, resulting in net accumulation of fine-grained terrestrial material. This sediment was slowly reworked and transported near the bed clockwise out of the bay, exposing corals to elevated turbidities for weeks to months. It appears that floods during low-energy conditions impact the health of the coral-reef ecosystems in the bay by reducing water quality and covering hard substrate suitable for coral recruitment. Episodic, energetic conditions, however, result in shorter residence times for fine-grained flood sediment in the bay. The often decoupled, episodic sediment delivery and removal processes further suggest that water quality in Hanalei Bay, and similar linked watershed-reef systems, are sensitive to changes in the frequency and intensity of floods and large wave events.

21A Watershed management & reef pollution
Monday 9 July, 1130, MR3

Addressing land based sources of pollution in Guanica, Puerto Rico

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Coral reefs have experienced an unprecedented decline in the Caribbean over the past 30-40 years and by some estimates the loss has been greater than 50% of live coral and over 90% of the sensitive and federally listed staghorn and elkhorn coral. In Puerto Rico scientists have noted that nutrient

and sediment contaminants have increased by 5-10 times pre-colonial levels on several occasions in the last 40-50 years. The 150 square mile Guanica watershed in Southwest Puerto Rico contains many of the land based sources of pollution threats found across a spectrum of coral watersheds. Watershed restoration efforts have had to traverse a broad range of implementation projects to be successful. The key restoration interventions being undertaken include: 1) river restoration to address eroding legacy sediment; 2) conversion of sun grown coffee to shade grown to reduce sediment export from high mountain areas; 3) efforts to restore the largest freshwater lagoon/wetlands in Puerto Rico, which historically acted as a filter for much of the watershed; 4) the construction of treatment wetlands at a wastewater plant discharging to Guanica Bay and 5) tracking and remediation of disparate sources of pollution from around the Bay and nearby towns, which include development on septic systems, illicit washwater and sewage discharges and leaking infrastructure. The presentation will highlight the efforts to construct treatment wetlands and track pollution sources in the watershed.

21A Watershed management & reef pollution
Monday 9 July, 1030, MR3

Assessment on sediment organic matter transportation using stable isotopes analysis

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Sedimentation is one of the major stressors to the coral reef ecosystem. The study was conducted in the Berau, East Kalimantan, Indonesia which is part of the Coral Triangle in the West Pacific, in order to trace the transportation of sediment organic matter to coral reef areas using stable isotopes analysis. The study area was divided into three transects: Transect 1, 2, and 3, representing the northern, middle, and southern parts of the Berau River mouth. Field work was carried out during dry, rainy season and shifting seasons, and a total of 126 sediment and 129 POM samples were collected. Results from the isotopic analysis revealed that $\delta^{13}C$ during the rainy and shifting season had lower values than the dry season, since soil erosion must be increased during the rainy and shifting seasons with heavy rainfall. About 10% of the total sediment samples had $\delta^{13}C$ values higher than -23‰, suggesting that most of sediments sampled were of terrestrial origin. Spatially, terrestrial sediments had reached around 60 km from the river zero point in Transect 1, about 80 km in Transect 2, and 70 km in Transect 3. $\delta^{15}N$ values of POMs in Transect 1 during the rainy season, fluctuated and was higher (around +10‰ to +20‰) in some points around coal mining and power plant sites, and some villages. This must be an indication of allochthonous sources of nitrogen organic matter, such as anthropogenic impacts and agricultural activities which produce isotopically higher organic nitrogen.

21A Watershed management & reef pollution
Monday 9 July, 1145, MR3

Anthropogenic factors and nutrient variability along the Coral Coast, Fiji.

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Coral reefs the world over are being threatened by anthropogenic factors, one of the most significant being nutrient enrichment of coastal waters. The Coral Coast region, in south-western Viti Levu, Fiji, is no exception to this threat. The region has undergone very rapid development since the 1970s, but few studies have been done to monitor the effects of such development on the water quality, or the fringing reefs that adorn the Coral Coast region. However, observations by local communities and the few sporadic studies conducted in the area, have shown progressive degradation of the fringing reefs and deterioration of the water quality. Water column nutrient concentrations only provided a snapshot of the status of water quality and showed high variability, but averages over a long period of monitoring showed a clear association between anthropogenic effects and water quality. Nutrient concentrations were highly variable, showed little association with season, but were strongly linked to rainfall. The results indicated the clear influence of pulse (storm runoff related) events on the nutrient concentrations in the water column. Control sites located furthest from human settlements and development, generally recorded lower nutrient concentrations than impacted sites, confirming the anthropogenic effects on water column nutrients. The biological communities on the fringing reefs reflected the status of nutrients in the water column. Recommendations are proposed for better management of nutrient sources on land for the protection of the water quality, and therefore promote healthier coral reef systems.

21A Watershed management & reef pollution
Monday 9 July, 1200, MR3

Managing the Great Barrier Reef from the paddock: enhancing agricultural extension

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Agricultural extension plays an important role in facilitating land management changes by rural landholders. This has been recognised in the Reef Water Quality Protection Plan 2009 (Reef Plan) as integral to increasing the rate of uptake of land management practices that contribute towards improving the quality of water entering the Great Barrier Reef lagoon. This presentation gives an overview of Reefocus Extension, a pilot program to enhance extension coordination and delivery to improve land management practices. Led by the Department of Employment, Economic Development and Innovation, this pilot worked with the sugarcane, beef cattle grazing, banana, mixed cropping, dairy and forestry industries in the Herbert and Johnstone River catchments of North-East Queensland. Based on the Reef Plan Extension and Education Strategy, it involved establishing a network to promote communication and coordination amongst stakeholders and alignment with other Reef Plan programs. Extension services and resources were targeted to achieve agronomic, economic and water quality benefits. Professional development and training also played a key role in building the capacity of extension practitioners and producers to assist in uptake of improved land management practices. Monitoring and evaluation was an integral part of this pilot, identifying successes and areas for improvement. This is being used to provide recommendations for Reef-wide extension coordination and service delivery. Outcomes and key lessons learnt will be presented.

21A Watershed management & reef pollution
Monday 9 July, 1250, MR3

Suspended sediment threatens larval development in a coral reef fish

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Increasing sediment input into coastal marine environments is having a profound influence on shallow marine habitats and their supported species. Coral reef ecosystems appear to be particularly sensitive, with increased sediment deposition and turbidity regimes being associated with declines in the abundance and diversity of coral reef fishes. Recent work has demonstrated that suspended sediment impairs habitat choice and foraging success of coral reef fish through a reduction in their ability to distinguish visual and chemical cues. However, it is unknown if suspended sediment affects larval development, which is a factor that could alter recruitment patterns in areas prone to high suspended sediment and flood plume exposure. In this study, we investigated if exposure to suspended sediment impairs larval development of *Amphiprion melanopus*, a coral reef damselfish. Specifically, larvae were subjected to four experimental concentrations of suspended sediment over four different exposure times. Gill development, growth rate, and body condition were assessed to categorize the impact of suspended sediment concentration and exposure on larval development. Impact groupings were mapped with *in situ* water quality data from flood plumes in the Great Barrier Reef in order to determine likely locations where suspended sediment and larvae could intersect and how the larvae may be affected. A sediment-induced impairment of larval development can have major effects on patterns of fish distribution, abundance and population dynamics.

21A Watershed management & reef pollution
Monday 9 July, 1115, MR3

Response of coral larvae to Deepwater Horizon oil and dispersants

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Acute catastrophic events can cause both significant disruption and damage in a short time period and may have devastating long-term impacts. In April 2010 the BP-operated Deepwater Horizon offshore oilrig exploded, releasing an estimated 4.9 million barrels of crude oil into the Gulf of Mexico. This study examined the potential effects of the blowout on coral larvae in the Florida Keys. Larvae of the brooding coral, *Porites astreoides*, and the broadcasting coral, *Montastraea faveolata*, were exposed to multiple concentrations of BP Horizon source oil, oil in combination with dispersant Corexit 9500, and dispersant alone under static constant exposure and analyzed for settlement success and survival. Exposure to the highest concentrations of source oil was found to negatively affect survival of *P. astreoides* larvae but had no affect on larval settlement. Source oil, in all concentrations examined, did not affect settlement or survival of *M. faveolata* larvae. Exposure to mid and high concentrations of oil in combination with dispersant and dispersant alone, however, significantly decreased settlement and survival

of *P. astreoides* larvae. Likewise, settlement and survival of *M. faveolata* larvae were significantly reduced when exposed to all concentrations of dispersed oil and to mid and high concentrations of dispersant alone. These results indicate that exposure of coral larvae to oil spill related contaminants, particularly dispersant Corexit 9500, will have negative impacts on settlement and survival, thereby affecting the resilience and recovery of coral reefs. Such information will be useful in the event of future oil spill disasters and clean up efforts.

21A Watershed management & reef pollution
Monday 9 July, 1230, MR3

Fluorescence in an inshore reef region

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Nutrients derived from riverine input are thought to pose a serious threat to the inshore reefs of the Great Barrier Reef (GBR). In this work, measurements of water turbidity, suspended sediment concentration, and water fluorescence were taken on fringing reefs close to the mouth of the Tully River. These reefs are amongst the most exposed to runoff of nutrients and sediments from farmland on the adjacent coast, as they lie within a few kilometres of the river mouth. Fluorescence, which is sometimes used as a proxy for chlorophyll concentrations (phytoplankton), was found to be highly correlated (r^2 up to 0.9) with suspended sediment concentrations. The highest fluorescence readings were not observed during or shortly after discharge events and fluorescence was generally not well correlated with discharge (r^2 less than 0.1) suggesting that fluorescence is not highly influenced by river output. Two possible explanations for this are either (a) fluorescence is not a good proxy for measuring the expected phytoplankton blooms or (b) that over short time scales the river discharge is not directly controlling primary production in this area.

21A Watershed management & reef pollution
Monday 9 July, 1745, MR3

21B Enhancing coral reef resilience through management of water quality

Reef Water Quality Protection Plan: making the Great Barrier Reef resilient

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The Reef Water Quality Protection Plan (Reef Plan) is a joint agreement between the Queensland and Australian Governments to improve the quality of water flowing into the Great Barrier Reef. Reef Plan's scope is to address non-point source pollution from broad-scale agricultural land use. It is underpinned by clear and measureable targets, clear accountability and a comprehensive and coordinated monitoring and evaluation program. There are eleven key actions under Reef Plan that contribute to achievement of these targets. Twelve different government and non-government partners are accountable for delivery. Major on ground change is being achieved through grants, regulations, extension and industry programs which are all contributing to achievement of Reef Plan's performance targets. Overall, progress in implementation has been significant and partners feel positive, engaged and committed to Reef Plan. Partners are now turning their minds to Reef Plan's next major milestone in 2013. This will involve assessing progress in achieving targets as well as reviewing new scientific knowledge generated by a significant investment in research. This will help identify what steps may be required to help deliver on Reef Plan's longer term 2020 goal of ensuring the quality of water entering the Reef from adjacent catchments has no detrimental impact on the health and resilience of the Great Barrier Reef.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1030, Plenary Hall 2

Synoptic scale monitoring supports the coral reef eutrophication threshold model

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Synoptic scale monitoring of chlorophyll a (Chl a) using field measurements and satellite imagery provides information on the causes and the extent of impacts of increased fertility (i.e. eutrophication) in the Great Barrier Reef lagoon. Much of the increased fertility can be attributed directly to increased loads of nutrients (e.g. nitrogen, N and phosphorus, P) exported via discharges from coastal developments (urban, industrial and agricultural). In addition, the activity of nitrogen fixing bacteria and cyanobacteria (e.g Trichodesmium spp.), which are contributing to the problem by fixing substantial loads of 'new' nitrogen, can also be monitored to some extent using satellite imagery. The impacted regions are characterised by annual mean Chl *a* concentrations exceeding the suggested eutrophication threshold concentrations (ETC-Chl *a* ~0.3-0.5 mg.m-3) or the recently defined Trigger Levels (TL-Chl a ~0.45 mg.m-3). In these impacted regions many shallow-water reefs are showing signs of low resilience to

disturbance and hence are degraded, whereas those in regions where annual mean Chl *a* values are less than the proposed ETC-Chl *a*, show no evidence of degradation. Various studies have identified a direct link between elevated Chl *a* concentrations and the growth of larvae of the crown-of-thorns starfish (*Acanthaster planci*) and jelly-fish. Hence the synoptic scale monitoring can be used to identify regions which will promote the growth of such larvae and the likely directional transport of such larvae. Overall historic and contemporary synoptic scale monitoring provides support for the proposed eutrophication threshold model (ETM) for coral reefs.

21B Enhancing coral reef resilience through management of water quality
P227

Biochemical and molecular indicators for pesticide and thermal stress on damselfish

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Inshore reefs face multiple stressors, including pollution and ocean warming. To better understand the sub-lethal impacts on reef fish, juveniles of the damselfish Acanthochromis polyacanthus were exposed to: a) the widely-used insecticide chlorpyrifos (CPF); b) elevated but environmentally relevant temperature and c) the combination of both stressors. The functioning of the nervous system was evaluated by measuring cholinesterase (ChE) activity, oxidative stress was assessed by measurements of the coenzyme Q (CoQ) redox balance and detoxification pathways by measuring glutathione-S-transferase (GST) activity. Expression patterns of stress-responsive genes were also investigated, namely GST, Catalase, Heat-Shock Proteins and Elongation Factor 1 alpha. Fish exposed to 1, 10 or 100 µg/L CPF for 96 h exhibited inhibition of 26%, 49% and 53% in muscle ChE activity respectively, while temperature induced a drastic and previously unreported decrease in ChE activity in fish exposed to 32°C (50% reduction compared to fish at 28°C). CoQ redox balance was shifted towards its antioxidant form after 6 h of exposure to 10 µg/L CPF and exhibited a decrease in fish exposed to 34°C compared to 28°C during the early stages of exposure. Simultaneous exposure to both stressors revealed no interaction, but induced a general shutdown of transcription after 6 h of exposure to 10 µg/L CPF. Overall, our results indicate that CPF and temperature both impair the functioning of a key neural enzyme and induce a response to oxidative stress, while the combination of stressors profoundly affects the molecular processes in A. polyacanthus.

21B Enhancing coral reef resilience through management of water quality
P237

Assessing GBR water quality compliance using earth observation data

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To effectively inform and support the management of the Great Barrier Reef (GBR) World Heritage area, accurate and spatially comprehensive water quality information is required. To meet the environmental reporting needs of the Great Barrier Reef Marine Park Authority (GBRMPA), it was necessary to ensure accurate retrieval of water quality variables from satellite imagery. These time series were subsequently translated into management relevant water quality information. *In situ* optical measurements of the coastal waters in the GBR have shown highly variable inherent and apparent optical properties, resulting in low accuracy for the global ocean colour algorithms in these waters. To enable a reliable and valid mapping of water quality variables we applied physics-based and regionally parameterised coastal ocean colour algorithms to spectral data of the Moderate Resolution Imaging Spectroradiometer (MODIS). GBRMPA released specific water quality guidelines in 2009 providing threshold levels for environmental reporting of the Marine Park. The assessment of the exceedance of water quality guidelines using remote sensing data was implemented for the Reef Rescue Marine Monitoring Program for two key water quality variables: total suspended solids as an indicator of water clarity and a proxy for resuspension or catchment sediment delivery; and chlorophyll as an indicator of phytoplankton biomass and a proxy for nutrient availability. In 2009-2011 chlorophyll concentrations exceeded the water quality guidelines' thresholds for larger portions of the GBR Lagoon than in previous years, reflecting higher primary productivity, due to larger flow conditions in most of the catchments in the GBR and associated nutrient delivery.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1455, Plenary Hall 2

Macro-bioerosion in *Porites* corals from the northern South China Sea

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The potentially negative effects of bioerosion on tropical coral reefs are well documented, but few studies have quantified the direct impact of macroborers on subtropical coral communities. In this study, internal macro-bioerosion of *Porites* corals was examined at Weizhou Island and Daya Bay, northern South China Sea (NSCS). Twenty-five massive *Porites* corals were cut into slabs and photographed to identify internal bioeroders and the degree of bioerosion caused by each bioeroding group were evaluated using image analysis. The bioeroders included sponges, bivalves, barnacles and sipunculid and polychaete worms. The most important borers were filter-feeding bivalves (*Lithophaga* sp.) and sponges (*Cliothosa* sp. and *Cliona* sp.), while worms showed relatively low bioerosion activity. Furthermore, there was no evidence that echinoid bioerosion or fish grazing has obvious effects on coral communities, though they were common on tropical reefs. *Porites* corals near the coastal urban and aquacultural areas were heavily bioeroded. Total internal bioerosion decreased significantly with distance from coastal urban and aquacultural areas. Abundances of bivalves and sponges decreased most significantly. We suggest that this bioerosion pattern is related to water quality. Increasing abundances of nutrients and productivity, and possibly water temperature, stimulated bioerosion. We appeal to local governments to develop appropriate management strategies to maintain a functional environment for these coral communities.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1450, Plenary Hall 2

Great Barrier Reef Report Card: measuring progress towards our targets

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The Queensland and Australian Governments have made a commitment under the Reef Water Quality Protection Plan (Reef Plan) to report annually on the health and resilience of the Great Barrier Reef and on progress towards a suite of performance targets. The Reef Plan Report Card is a key output of the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program which is implemented over a 400,000 square kilometre land area and covers a coral reef system stretching 2300 kilometres along Australia's east coast. The Paddock to Reef Program represents an investment by the Australian and Queensland Governments in excess of $40 million. Implementing the program is a collaborative effort involving more than 20 organisations, including governments, industry partners, research organisations, regional natural resource management bodies and individuals. The Reef Plan Report Card is a 'world first' water quality assessment of one of the largest World Heritage sites on the planet. It incorporates metrics for land management practice adoption, catchment condition, catchment pollutant loads, and reef water quality and ecosystem health. The results of the First Report Card showed that the reef was in moderate condition overall; however pollutant loads leaving the catchments and entering the reef were five to nine times the natural loads for total suspended solids, total nitrogen and total phosphorus. The second Report Card reports on changes from the baseline and progress towards Reef Plan goals and targets. This information is crucial to setting the future policy direction of the Reef Plan.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1130, Plenary Hall 2

***Aiptasia pulchella* as a cnidarian representative in tropical marine ecotoxicology**

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The preferences expressed in the ANZECC and ARMCANZ (2000) guidelines, for toxicity data from five regionally relevant species, from four taxonomic groups, cannot currently be met for tropical marine ecosystems due to a lack of available standard test methods using tropical species. The practice of using temperate species for protection of tropical ecosystems has been widely questioned and heavily criticized, hence there is need to develop standard test methods for tropical marine species. *Aiptasia pulchella* (Carlgren 1943, validated by Fautin 2006) is a sea anemone found across the Pacific Ocean and throughout the tropics. This species thrives under optimal laboratory conditions and has been used extensively in cnidarian research, including biology, photophysiology, bleaching mechanisms and algal-host symbiosis. We investigated the potential for this species to be used as a cnidarian representative for tropical marine ecotoxicology. This presentation reports on laboratory culture conditions and acute (96h) and sub-chronic (28d) lethal and sublethal effects from trace metals, and the phenylurea herbicide diuron. Results of these tests have shown that this species is sensitive to toxicants with 96h LC_{50} values for Cu between 69-92 µg/L, and 14d LC_{50} values and 28d EC_{50} values being much lower (9-17µ/L). Significant differences in measured PAM

parameters occurred within 2h of exposure to 10µg/L diuron, and within 24h at concentrations 0.1µg/L diuron. This work focuses on optimising reliable, quantifiable sub-lethal test endpoints for the use as a standard test method.

21B Enhancing coral reef resilience through management of water quality
P228

Enhancing coral reef resilience through management of water quality

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Recovery or maintenance of a preferred, coral-reef dominated stable state has been a strong focus of coral reef science and management. Globally, coral cover on tropical reefs has declined substantially, and less desirable alternative stable states such as those dominated by macro-algae are now more common. Such phase shifts in coral reefs are generally associated with chronic stressors such as pollution, over-exploitation, and diseases. While many researchers have concluded that land-based sources of pollution degrade downstream coral reefs, the reversibility of this system of environmental degradation has not been established. To identify successful studies of reduction in land based sources of pollution that could be used as a model to improve reef water quality, we summarise the most recent evidence for responses in coastal marine water quality and ecosystems to land-based management efforts. For each pollutant, we first review the global evidence for changes in fluxes to coastal and coral reef environments and outline how corals are affected by resultant changes in water quality. We then examine the effectiveness of land-based efforts aimed at restoring pollutant fluxes to coastal and coral reef environments and reversing ecosystem degradation. Our findings confirm that, whilst several studies have documented reductions in terrestrial pollutant fluxes to coastal marine environments, so far this has rarely, if ever, translated into desired ecological outcomes in these ecosystems. We conclude by recommending substantial changes to current approaches to land-based restoration efforts to realize the reversal of coral reef ecosystem degradation, and enhance resilience of preferred, coral-reef dominated state.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1000, Plenary Hall 2

Load estimation and uncertainty in GBR catchments: a data assimilation approach

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The export of pollutants from coastal catchments within Australia, has important implications for the health of the Great Barrier Reef (GBR). As a result, there is a strong need to identify appropriate statistical methods for reliably estimating annual pollutants loads (with some measure of uncertainty) based on monitoring data and knowledge of catchment processes to assess progress towards defined loads targets. Current methods for estimating loads either rely solely on monitoring data, where a statistical framework is developed to account for key sources of uncertainty related to concentration and flow. Alternatively, a catchment model is used to calculate loads, which consists of a number of deterministic relationships underpinned by the physical processes of the system. In this type of modelling framework, the model is calibrated with event monitoring data but no measure of uncertainty is estimated. Data assimilation explored within a hierarchical Bayesian modelling (HBM) framework is a useful modelling paradigm to explore in this context, as it takes into account the uncertainty in the physical processes as well as the observed data. We outline a Bayesian Hierarchical Modelling (BHM) framework for quantifying loads and uncertainties using the Weany Creek site in the Burdekin catchment and outline extensions of this model for subcatchments and catchments that incorporate space and time.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1245, Plenary Hall 2

Does nutrient enrichment contribute to coral bleaching in Fiji?

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The threat of global warming on coral bleaching events are well document, however, recent studies have suggested that poor water quality due to nutrient enrichment may jointly act with heat stress to upset long-evolved relationships and ecosystem processes that have evolved in oligotrophic settings. Nutrient enrichment of coastal waters is a problem worldwide, and is expected to intensify along with increasing global population and migration to coastal

areas. This study seeks to investigate the linkage between nutrient enrichment and coral reef health around Fiji. Geographic patterns of coral bleaching around Fiji were collected from long-term monitoring sites and integrated into a Bayesian belief network model, to outline the synergistic effects of heat and nutrient flux as joint stressors of coral bleaching mechanisms. Photosynthetic parameters of *Acropora* spp. were examined both experimentally and *in situ* using a Diving-PAM and oxygen microsensors along a water quality gradient, to quantify the impacts of nutrient stress on coral health. If we can better understand the relationship between nutrients and coral bleaching events, more effective, scientifically appropriate management strategies and restoration initiatives may be put into place, strengthening overall coral reef conservation efforts. This study hopes to support the expressed belief that improved management of reefs may increase the likelihood of coral survival into the future.

21B Enhancing coral reef resilience through management of water quality
P229

Pollution increases climate impacts on coral

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Elevated sea surface temperatures (SST) pose risks to corals by affecting adult populations as well as reproduction and recruitment processes. Whilst improving water quality through land management practices is a key strategy to maximise the resilience of corals to a changing climate, there is little direct research to support this approach. Here we describe two experimental approaches to quantify how SST interacts with two contaminant types to affect coral larval metamorphosis and photosynthesis in adult corals. The metamorphoses of two broadcast-spawning coral species, *Acropora millepora* and *A. tenuis* were assessed when exposed to both increased SST and copper (Cu) contamination. A fully parameterised model incorporating both the influences of Cu and SST was used to show that Cu contamination reduced the thermal tolerance of both species of coral larvae. The photosynthetic efficiency of adult *A. millepora* was assessed when exposed to three agricultural photosystem II herbicides at four temperatures. Environmentally relevant concentrations of each herbicide increased the negative effects of thermal stress on coral at 31℃ and 32℃. Mixed model analysis of variance showed that the effects of elevated SST and herbicide on photosynthetic efficiency of coral symbionts were generally additive. Reducing the concentrations of contaminants can protect larval metamorphosis and primary production in coral symbionts from increases in SST equivalent to 1-3℃. Our results demonstrate that pollution increases the vulnerability of corals to elevated SSTs and effective management of local water quality can reduce negative effects of global stressors such as elevated SST.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1400, Plenary Hall 2

Environmental correlates of coral communities exposed to multiple disturbances

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Decline in coral reef condition results from interactive effects of multiple stressors and is often linked to geographic proximity to human influences. However, few studies examine a comprehensive suite of both stressor and response variables, often focusing on an *a priori* subset of water quality. For example, decadal-scale losses in hard coral cover in Singapore have been qualitatively attributed to increased sediment loads, but the responses of key reef components to environmental conditions have not been quantified. This paper presents a broad-scale analysis of environmental correlates of coral reef community and functional structure in Singapore in relation to gradients from potential impact sources. Data from 10 reefs from 2008 to 2010 showed that community structure was initially distinct, but there was a gradual convergence of community structure associated with a general shift towards greater abundances of algae and silt-covered substrata. Concomitant with this are changes in predominant coral morphologies, with losses in topographic complexity. Interestingly, nutrients, pH, petroleum hydrocarbons, primary and secondary production, but not suspended sediments, were identified as major influences on observed patterns. Information on coral reef condition under present-day disturbance regimes is especially crucial to further understanding of future reef biodiversity, functioning and associated ecosystem services in the face of global climate change. Detailed knowledge of the environmental drivers of reef decline is therefore vital to enhancing reef resilience through successful management of local impacts such as altered water quality.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1145, Plenary Hall 2

Are off-reef water samples a good proxy for on-reef conditions?

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Elevated nutrient loading is a major threat to coral reef ecosystems. Management of this threat frequently involves regular monitoring of water quality and action linked to relevant water quality guidelines. In most water quality monitoring programmes, sampling stations are situated some distance from the reef. However, the morphology of corals and coral reef are known to affect meso-scale uptake and transport processes, which may result in distinct differences in the concentrations of dissolved and suspended material over short distances away from the reef. To investigate the differences in measured nutrient contents between on-reef and off-reef sampling, total suspended solids and concentration of six nutrient species were compared between water samples collected 0.5 metres above the reef on fringing reefs using SCUBA and that collected via Niskin bottles from discrete depths along the water column off-reef. Principal Component Analysis showed that phosphate, ammonia and total suspended solids levels were the main contributors to the separation between the two sampling locations. Concentrations of TSS, NH_3 and PO_4 were significantly lower in on-reef samples. Furthermore, measurements from on-reef samples were not significantly correlated with that from off-reef samples. The results demonstrate that measurements from water samples collected off-reef are a poor proxy for those directly on the reef, which has implications on reef management. The findings highlight the importance of understanding differences in processes such as micro-hydraulics, and nutrient cycling and sequestration between reefs and their adjacent water, and in particular a need to examine the interactive effects of biota and nutrient levels.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1415, Plenary Hall 2

Increased temperatures and eutrophication inhibit growth of the photosymbiont-bearing foraminifera, *Marginopora vertebralis*

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This study investigates the growth response of *Marginopora vertebralis* to enhanced terrestrially derived nitrogen and phosphate under field and laboratory conditions. The field studies were conducted around the Whitsunday Islands in the Great Barrier Reef (GBR), Australia, once during a peak flooding period and once during the dry season. During the summer flood season, terrestrially derived runoff from the Proserpine Catchment increased the dissolved inorganic nitrogen and particulate phosphate by two to five-fold throughout the study site. Increased exposure to nutrients derived from terrestrial runoff negatively impacted the growth rate of M. vertebralis in the field and in a comparative laboratory experiment. The field study showed a clear effect with proximity to the river mouth and the intensity of the river discharge. Growth rates were higher in the reduced terrestrial runoff at the offshore sites. When *M. vertebralis* was exposed to naturally enriched dissolved inorganic nitrogen and phosphate in the laboratory experiments, a 51% and 37% growth rate reduction, respectively, was found compared to ambient controls. Nutrification likely causes destabilisation in the coupling of photosynthesis and growth within the photosymbiont by restricting photosynthate translocation to the host. In addition to nutrient effects, growth rates were also significantly lower in the warmer (28°C) treatment than the cooler temperature (22°C). Overall, the study finds evidence that management of local stressors (in this case nutrient runoff) might ameliorate impact of climate change (increased temperature) on calcifying photosymbiont-bearing organisms.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1200, Plenary Hall 2

Biogeochemical conditions and sessile foundation species composition in coral reefs

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Both natural and human-induced changes of the biogeochemical environment have been reported to threaten coral reef ecosystems (e.g., nutrient and organic matter input, ocean acidification). Meanwhile, coral reef ecosystems are controlled by various physical, chemical and biological factors. Such complexity hinders mechanistic understanding of the deterioration of coral reef ecosystems. Taking account of the relative importance of potential factors, key factors controlling biogeochemical conditions as well as community structures, needs to be ensured, to establish sound ecosystem management strategies. We sampled 36 stations on the

coral-reef-dominant coasts of Okinawa Island, southwestern Japan, for water chemistry (e.g., pH, salinity, DO, turbidity), biogeochemical properties (C:N, C and N stable isotopic signatures) of fine particles, and physical environmental variables (e.g., geomorphology at multiple spatial scales, current strength). We also quantified community composition of sessile foundation species by analyzing digital photographs of benthic quadrats from the study stations. Applying multiple statistical approaches, we tested the relative importance of environmental factors potentially controlling/affecting biogeochemical conditions and community structure of sessile foundation species in coral reef ecosystems. In particular, we focus on effects of freshwater input, anthropogenic nutrients, geomorphological and hydrodynamic conditions, and spatial scales of the analyses. We aim to answer two questions: (1) what are key factors controlling the biogeochemical environment of coral reefs? (2) where/when does the biogeochemical environment significantly affect coral reef communities?

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1215, Plenary Hall 2

Water quality variability in the inshore Great Barrier Reef lagoon

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Water quality is the collective term for a group of environmental variables (e.g., dissolved and particulate nutrients, turbidity, salinity, chlorophyll) that affect and control pelagic and benthic communities. Long-term data from the inshore Great Barrier Reef (GBR) lagoon show that water quality variability is mainly driven by seasonal processes such as river floods and by sporadic wind-driven resuspension. Extreme weather events such as wet season floods are important drivers of water quality for periods of weeks to months and are a significant disturbance factor for inshore ecosystems such as coral reefs and seagrass beds. Sites close to river mouths have high turbidity levels and elevated chlorophyll a and phosphorus concentrations, often exceeding GBR water quality guideline values. The analysis of the longest available water quality time series for the GBR (1989-2010) showed that most water quality variables display significant long-term trends with a period of elevated concentrations during the late 1990s to early 2000s. These high values were explained by very high rates of vegetation clearing on the adjacent catchments, coinciding with three major river flood events. This is the first direct evidence, albeit correlative, that catchment activity (i.e. land clearing) affects marine water quality. Future improvements in GBR catchment management are expected to improve inshore marine water quality; however, we propose that the reduction of event loads should be a priority. Long time series will be required to unequivocally detect improvements in marine water quality because of the highly variable baseline and lags in ecosystem responses to load reductions.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1015, Plenary Hall 2

Extreme environmental conditions disproportionately force change in coral community composition

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It is widely accepted that coral communities vary along environmental gradients of light availability, sedimentation, nutrients and salinity. However, the majority of such studies are spatially and temporally limited and it is difficult to determine how universal those response patterns are. In addition, the environmental factors used to explain coral responses often only represent mean conditions without considering their substantial variability. Here we construct a simple theoretical model of the effects of catchment runoff on coral reefs based on published studies. We then compare the model to data from seven years of coral community monitoring on 32 reefs in turbid coastal waters of the Great Barrier Reef. The temporal replication within our data allows us to demonstrate that coral communities exhibit increased signs of stress, e.g., high incidence of disease and reduced abundance of juveniles, following periods of higher than median river flow in adjacent catchments. We conclude that the combination of acute events, followed by a period of medium-level stress are likely to outweigh the effects of chronic environmental change such as the gradual build up of turbidity or nutrients. Our data suggest that coral colonies that survive acute and medium term extremes are likely to also survive longer periods of lower, chronic environmental pressure. The importance of measuring responses to environmental extremes rather than long-term means has ramifications, not only for the sampling strategies used to monitor or identify downstream effects of runoff, but also for the management strategies employed to limit downstream impacts to coral reefs.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1445, Plenary Hall 2

Water quality benefits of improved agricultural management practices

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Chemical and sediment losses from agricultural lands are threatening marine and freshwater ecosystems in many parts of the world. This is an acute problem in Australia, where the health of Great Barrier Reef (GBR) ecosystems is threatened by increased pollutant loads from agricultural lands, and Governments have enacted policies to reduce pollutant exports. These policies raise the question of how to identify changes in land management that will effectively reduce exports. The size of GBR catchments precludes detailed modelling investigations, especially within the time scale of policy implementation. Therefore, we use conceptual frameworks between agricultural land management and river pollutant exports for two contrasting agricultural pollutants posing threats to the health of GBR ecosystems; Dissolved Inorganic Nitrogen (DIN) and fine sediment (fine silt and clay). We apply the frameworks to show that inputs of N fertiliser, especially when considered relative to crop N off-take (i.e. N Surplus), is the primary driver of anthropogenic DIN losses from agricultural land to rivers. Similarly, land condition controls anthropogenic fine sediment losses. We evaluate various scenarios of management practice change and predict that widespread adoption of the most extreme scenarios would approximately meet governments' water quality improvement targets. However, this outcome is unlikely for two reasons. Firstly, these extreme scenarios have not been widely tested, a necessary process before their adoption by farmers. Secondly, there are substantial time lags between practice change and water quality improvement. Our approach should be applicable to other pollutants (e.g. total N or pesticides) and other large catchments.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1430, Plenary Hall 2

Salinity as a structuring force for near shore coral communities

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Corals in near-shore environments are particularly vulnerable to the effects of climate change, especially in those locations where the coastal fluvial landscape has been altered by human activities. The investigation of salinity responses of corals from reefs exposed to river plumes provides insight into the structuring role of monsoonal flooding on coral assemblages and their long-term prognosis. In this study, the effects of hyposalinity exposure on corals acclimated to nearshore conditions were examined for five genera of hard corals. Fertilisation success, larval survivorship and settlement success showed clear trends amongst genera. Unsurprisingly, those species of massive corals that are most common in shallow reef flat environments were the most tolerant of salinity stress as larvae. The most susceptible species were the branching and table *Acropora*. These trends were repeated in adult corals subjected to prolonged hyposaline conditions. Measurement using tissue lipid concentrations as a proxy for energy reserves reflected the same patterns of stress tolerance. Duration of exposure at moderately low salinities (22-25psu) was a critical transition factor for survivorship of the most sensitive species: pulses of low-moderate salinity such as might be associated with severe rainfall events were well-tolerated, but prolonged exposure caused rapid declines in lipid reserves and survivorship. These results demonstrate that severe flooding events, such as affected the Gulf of Thailand in 2011 can drastically change the community structure of nearshore reefs and have lasting impacts on the function and replenishment of crucial nearshore habitats.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1115, Plenary Hall 2

Using statistical emulators to facilitate uncertainty quantification of pollutant loads

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The Great Barrier Reef can be greatly affected by the export of pollutants from coastal catchments. The associated pollutant loads can be calculated with deterministic catchment models. Such models, which include relevant physical processes, are highly nonlinear and can be somewhat expensive to run. In addition, many different parameterizations are included in these models and the associated parameters and, in some cases, the parameterizations themselves are not known with certainty. An important statistical problem is to quantify the implications of this uncertainty in the presence of limited observations and, in some cases, to provide more robust parameter or process estimates. Statistical emulators provide an

inexpensive way to approximate deterministic models in a stochastic environment that can facilitate the uncertainty quantification. In particular, we focus on so-called first-order emulators that follow more closely the etiology of the process as compared to traditional emulators, which focus more on modeling dependence structures. We discuss these models within the Bayesian hierarchical modeling paradigm.

21B Enhancing coral reef resilience through management of water quality
Friday 13 July, 1230, Plenary Hall 2

21C Exploited lagoons

Sustainable development of pearl farming industry in French Polynesia

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The Tahitian pearl farming industry plays a major socio-economic role in French Polynesia, with around 66 million euros worth of pearls exported in 2009. In an increasingly competitive market the production of high quality pearls becomes essential to maintain the long term profitability of this industry. In this context, the Ifremer in close collaboration with the 'Service de la Perliculture' (French Polynesian government agency) has developed a research project on the ' Sustainable development of pearl farming'. Its aim, in accordance with the concerns of pearl farmers, is to propose methods and tools that will increase superior pearl quality production that will support the sustainable development of pearl farming in French Polynesia. Researchers are organized in 3 axis: i) understanding the animal physiology (larval development, growth, rearing and reproduction), with the aim to breed families of graft donor oysters selected for their capacity to produce pearls of particular colours and/or rapid growth, ii) understanding the pearl formation by studying the grafting processes, the biomineralization mechanism and the influence of environment, with the aim to increase superior pearl quality production. iii) understanding bivalve larval dispersal and pearl oyster recruitment in the lagoon, with the aim to optimize spat collection strategies. This research is achieved through large collaborative projects regarding the 'Improvement of the Pearl Quality' (ADEQUA) or 'Integrated management and adaptation of pearl culture in French Polynesia' (French National Research Agency, POLYPERL). The results presented will summarize our current investigations regarding these projects.

21C Exploited lagoons
Tuesday 10 July, 0945, MR3

Sampling protocol effects on the assessment of species diversity in exploited lagoons

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We have quantified the impact of variation of several key-features of the observation protocols on the assessment of some of the main components of coral reef fish diversity. We, in particular, compared the assessment of diversity patterns obtained through the use of data collected by Underwater Visual Censuses (UVC) and by underwater video (the two kinds of data being sampled simultaneously) for different levels of anthropogenic conditions. In addition, this work assessed the variability of the response of some of the main complementary diversity components in the function of progressive reduction of data accuracy (e.g. abundance vs. presence-absence), the progressive reduction in scope of species lists considered (i.e. indices assessed on all species observed or only on a limited number of species belonging to a set of pre-determined families, etc.), and on the aggregation of taxonomic levels (e.g. information to the species level vs. information aggregated to the genus level). We performed this approach on a set of data collected in the Seychelles Plateau (Indian Ocean) and sampled according to the 'point count' technique. The study sites have been selected in such a way as to cover a wide range of anthropogenic conditions (highly exploited/urbanized sites vs. protected area). Finally, our work might provide tools and knowledge that are directly transferable to the diversity observation and management networks that are currently being developed worldwide at regional and biogeographical scales (e.g. GOPS, etc.).

21C Exploited lagoons
Tuesday 10 July, 1000, MR3

Interactions between pearl-oyster culture and water-column in French Polynesia lagoons

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Bivalve rearing causes major changes in ecosystem functioning and especially affects benthic-pelagic relationships. Cultivated filter feeders (bivalves and associated organisms) exert two antagonistic effects on the water column: (1) release of a large amount of nutrient (mainly NH_4^+) may enhance phytoplankton production (bottom-up effect) and (2) top-down effect through grazing pressure, controlling phytoplankton community and possibly driving a shift in species composition. In French Polynesia, pearl oyster culture spreads over 27 islands and represents the second most important source of revenue after tourism. This industry, based on exploitation of natural stock of *Pinctada margaritifera*, is strongly dependant on planktonic ecosystem functioning. Here, we propose an *in situ* investigation of the relationships between pearl oyster culture and the water column of coral reef lagoons in French Polynesia. Because pearl oysters are suspended in the water column, we are most interested in pelagic processes, specifically nitrogen exchanges, known as the limiting element for primary production in these ecosystems. Our first results indicate NH_4^+ production of between 0.25 and 1.5 µmol/h for 1g dry tissue weight. This is in agreement with mesocosm studies for *Pinctada margaritifera* or *Pinctada mazatlanica*. Role of biofouling in these interactions will also be assessed, because even if they are mentioned in several studies, their role remains largely unstudied. Moreover the trophic link between oyster and associated fauna could exist and affect ecophysiological function of pearl oysters (especially sex shift) by changing environmental conditions. Growth and reproduction of pearl oysters are therefore also studied in this context.

21C Exploited lagoons
Tuesday 10 July, 1015, MR3

Giant clam fisheries in French Polynesia: benefits, constraints and new issues

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Across the Pacific, giant clam over-fishing has led to a critical depletion of their natural stocks. To stop this trend, since 1985, Tridacnidae species have been protected by the Washington convention. With remarkable standing stocks of giant clams *Tridacna maxima*, and the highest densities recorded in the world, French Polynesia is of particular importance. Giant clams are highly appreciated locally, as they form the traditional meal. Over the last decade, as standing stocks in Tahiti and nearby islands have collapsed, a small fishing industry has progressively been developed in other islands to respond to the local market demand. This fishery is responsible for an annual transfer of 70 tons of giant clam flesh. Aware of the needs for species conservation, and considering that giant clam exploitation can also be a potential source of development for these remote islands, local authorities have supported scientific works on clam population assessment, dynamics, habitat and fishery practices, and exploration of a new issue: spat collection, occasionally called Postlarvae Capture and Culture (PCC). While a success story is confirmed after re-introduction of clams in protected areas, the question of sustainability of this new activity needs to be explored more deeply, with respect to the economical issues of such production. Furthermore, sanitary constraints, due to the emergence of ciguatera-like poisonings after clam consumption observed in other zones in the Pacific, are studied. Preliminary investigations have been conducted to test if cyanobacteria may be responsible for this contamination. Definition of a management strategy, based on co-management and participative action-research approaches is ongoing.

21C Exploited lagoons
Tuesday 10 July, 0930, MR3

Specific proteins extracted from Tahitian pearl oyster: *Pinctada margaritifera*

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Tahitian black pearls are generally obtained in *Pinctada margaritifera* by introducing an *Amblema plicata* nucleus and a graft from a *Pinctada margaritifera* donor's mantle, into the pearl bag. This begins the biomineralization process to produce the black pearl. The nucleus, made from shell, consists of calcium carbonate (aragonite) and an organic matrix

containing proteins synthesized in the mollusk mantle. We hypothesize that immuno-compatibility issues are induced in at least one *Pinctada* spp. when these proteins make contact with the graft during pearl bag development. This can cause mortality in the oyster, rejection of the nucleus or pearl defaults. We evaluated the protein pattern of mantle and extrapalleal fluid for two bivalves to investigate which proteins are specific and could be involved in the biomineralization process. Proteins were separated by SDS-polyacrylamide gel electrophoresis. Many proteins migrate in the same pathway in both bivalves. In our experimental conditions, one protein specific to the *Pinctada margaritifera* pearl oyster (MW= 204,000) was identified. This protein is present at a lower level in the mantle and more substantially in the extrapalleal fluid. This suggests the protein is secreted intensively by the mantle and stored in the extrapalleal fluid, where the proteins are synthesized by the mantle to form the organic matrix of the shell. This protein was electro-eluted to proceed with sequencing and identification. Future research will aim to determine whether this protein is important for biomineralization and useful for improving pearl quality.

21C Exploited lagoons
P230

Theme 22. Social, economic & cultural perspectives

22A Cultural, political & historical dimensions or coral reef management

Strengthening local management through education and science in Solomon Islands

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Global and regional attention on management of marine resources in Melanesia has increased dramatically over the past decade. Whilst there have been many successes, the diversity of governance and tenure systems makes the implementation of regional efforts challenging at the local level. Whilst it is generally accepted that a 'bottom up' community based approach is the most effective in Melanesia, in the Solomon Islands a lack of clear tenure and governance at the local level has limited the success and spread of this approach. Many communities in the Solomons have a history of top-down 'chiefly' control that has only recently been eroded. With the increasing desire for cash and land ownership, external resource management interventions can be used by a handful of opportunists to raise status, power and tenure claims. In some cases this can lead to attempts at bottom-up management becoming a top-down regime without broader community support or understanding. Five unique case studies from Solomon Islands will be used to demonstrate management success under a range of governance and tenure systems. In addressing some of these challenges we have focused on providing the foundations for resource management success in terms of education, training and applied science. An example from Roviana Lagoon in the Solomons demonstrates how scientific results can be incorporated with traditional knowledge in planning marine reserve networks. The process focuses on active participation design, implementation and reporting phases to achieve successful implementation.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1500, Sebel Kuranda

Extracurricular learning on the conservation of Brazilian reef environments

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This study aimed to investigate attitudes regarding the conservation of reef environments in the Fernando de Noronha Archipelago before and after a series of interventions designed to increase student's knowledge of these ecosystems, and to promote environmental awareness. Students (grades 5-8) were engaged in several educational activities, including the creation of a Reef Environment Museum at the local public school. We conducted student questionnaires before and after these activities in order to compare students' knowledge. Initially, according to the students' perceptions, corals and reefs were seen as valuable resources only when they generated economic advantages through tourism. After the interventions the students identified concepts that were more aligned with environmental conservation.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1245, Sebel Kuranda

Mesoamerican Reef Leadership Program: building a generation of conservation leaders

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Worldwide biodiversity loss is one of the most serious environmental problems faced by our generation. Despite possessing immense economic, cultural, and aesthetic value, marine ecosystems continue to deteriorate. The condition of the Mesoamerican Reef System (MAR), the second most biologically significant system of its kind in the world, is truly worrisome: 31% of the system's reefs are in critical condition; 38% in poor; 24% in fair; 6% in good; and 1% in very good condition. In an effort to arrest the reef's deterioration, the Mesoamerican Reef Leadership Program (www.liderazgosam.org) seeks to boost reef conservation by empowering emerging local leaders from the four nations of the MAR (Mexico, Belize, Guatemala and Honduras) with bolstered professional skills and technical assistance to develop innovative and replicable projects. It's a unified front in which participants work together in a close-knit network to conserve the MAR Region's coastal and marine ecosystems, while simultaneously striving to improve the livelihoods of local communities that depend on this threatened marine resource. The ultimate goal is to convert fellows' innovative ideas for tackling the main threats facing the reef into working solutions for reef conservation. Our fellows are working to

change the way people visit, fish, and exploit the region. They are key pieces in a mounting effort to reverse the region's condition and promote reef heritage throughout the region. "Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has" Margaret Mead

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1130, Sebel Kuranda

Whose sustainability? Top-down participation in MPA management in Indonesia.

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A review of a major community-based marine protected area program (CB-MPA) in an Indonesian island archipelago is the point of departure for this article. Despite a well-designed institutional structure to facilitate local participation, local knowledge about the CB-MPA is found to be low, and resource access and influence on decision-making in the program is negligible for the majority of islanders. At the same time, most of those who know about the program consider it as pertaining to the public authority only. These findings stand in contrast to evidence on non-formal ways of protecting and managing marine areas in the same geographical area but outside the formal MPA institutional framework. In particular, the article identifies a number of emergent rules-in-use in marine management, which operate parallel to legally established MPAs. It is argued that emergent forms of marine area protection such as non-formal self-organizing island exclusion zones (IEZ) offer, as yet, mostly unused potential for formal MPA development, particularly in those coastal and marine areas without traditional forms of marine and coastal management.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1700, Sebel Kuranda

Local perspectives on marine conservation: case of Biorock Project, Bali

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The study of local community perceptions is critical for the acceptance and success of marine conservation programs in Indonesia, a country of global marine biodiversity importance. Based on ethnography in the island of Bali, located at the western border of the Coral Triangle, this case study identifies and documents the coastal community perceptions of the joint marine conservation and coral restoration initiative "the Biorock project". This work reveals that Biorock implementation is inseparable from hegemonic discourse on sustainable development. Through utilizing the reception studies approach, this qualitative research shows how the local community conceptualize, adopt and utilize a discourse of sustainable development,, focusing on the way reception of the latter discourse shapes the community perception of the Biorock project. Varying representations of Biorock among the local community, and a trend towards conceptualizing sustainable development through the notions of the Hindu religion, are documented. Biorock, has contributed to the evolution of traditional customary law institutions through being partially integrated into them. Furthermore, revitalization of values similar to those of sustainable development, including socio-religious component of Tri Hita Karana, has sustained the Biorock project by generating more solid public support. Documented ways of reception of the discourse on sustainable development render ideas of marine conservation intelligible for the local community, and play an important role in leading perceptions towards the Biorock project in a more positive direction. Results have potential implications for marine conservation planning and coral restoration initiatives in the area.

22A Cultural, political & historical dimensions of coral reef management
P231

Customary marine tenure and contemporary resource management in Solomon Islands

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Much has been claimed about the positive benefits of the customary tenure (CMT) system in the South Pacific and its implications for resource management. In Solomon Islands the premise of effective community-based resource management (CBRM) as a contemporary management tool, rests to a great degree on CMT, but does CMT still provide a sufficiently strong foundation to support this premise? This research examined the social and environmental characteristics of a rural Solomon Islands coastal community that had

expressed a desire to implement CBRM. The research addressed the questions; what socio-cultural factors are related to CMT regimes and do these factors hinder or enhance the capability of the community to employ or maintain these regimes? Using primarily qualitative methodologies, this study focused on how marine resources are perceived and valued by different members of the community. The Western Province village is an example of one of many in Solomon Islands that have experienced a collapse in their traditional marine resource management systems. Most people in the village have lost their respect for their traditional leaders, and instead church leaders have more influence in their daily lives and can be influential in village decision making. Findings suggest that in communities where a common agreement on CMT no longer exists, stakeholders face a significant challenge in trying to achieve sustainably managed coastal marine resources through community based approaches. This challenge needs to be accounted for on a case by case basis as part of CBRM facilitation processes.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1115, Sebel Kuranda

Media analysis assists long-term monitoring of the Great Barrier Reef

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Long-term monitoring of coral reef ecosystems is plagued by a number of challenges, which are amplified when social dimensions of reef management are considered. Not only are data limited, but biophysical monitoring frameworks tend to be inadequate, and social change is complex, embodying cultural, political and historical factors that are not easily moulded to fit the conventional monitoring tools at our disposal. Given evidence that pressures on coral reefs are mounting worldwide, it is timely to consider expanding data sources for monitoring, and look to innovative approaches to fill knowledge gaps. In this paper we present research that highlights the important role the news media can play in this regard. News media is both a powerful driver of and reflector of social change; news publications have an unparalleled ability to frame and regulate the visibility of issues. The analysis of media representations of environmental issues is a growing field of research; it offers an inexpensive, non-intrusive way of capturing spatial and temporal change in the public discourse. Despite this, it remains an underutilised data source in monitoring programs. We report on how media analysis is being used in the Social and Economic Long-Term Monitoring Program for the Great Barrier Reef Marine Park. We show emerging findings that demonstrate the utility of this approach for identifying key drivers of change and societal perceptions of use, conservation and management of the Great Barrier Reef, which are essential elements for appropriately conceptualising and monitoring change.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1400, Sebel Kuranda

Increasing women's participation in community based management in Solomon Islands

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Men, women and youth all play important roles in fishing dependent families and communities in Solomon Islands and engagement by all is required for successful community based approaches to inshore marine resource management. However, cultural and educational constraints create barriers to the active involvement of women in management decision-making and men are often at the forefront when interacting with facilitation agencies. A gender analysis of several villages showed that women felt their marine resources needed to be looked after and managed, but they felt that they lacked the necessary knowledge and information to contribute fully to making management decisions. Driven by requests from village women, who were involved in participatory processes leading to implementation of Community Based Resource Management, we developed a program for women that addressed this need. Our program drew strongly on their own knowledge and focused on placing this in context of resource management, and improving understanding of biological concepts, their relation to management goals and how these relate to family health and well being. Participants have since felt empowered to utilise church gatherings and visits to neighboring villages to conduct formal and informal trainings of their own to further their goal of achieving better community co-operation in management, replenishment and protection of marine resources. An outcome of this research has been the formalisation of knowledge and goals of village women into informative and appropriate education materials that are being made available to assist women to participate more actively in effective management of their marine resources.

22A Cultural, political & historical dimensions of coral reef management
P232

Science communication for marine ecosystem management: what works for whom?

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Countless papers, talks, reports and websites recommend information and education campaigns (IEC) to address the continuing degradation of coral reef systems through human activity. Less addressed is what impact science and conservation communication activities have on people's awareness, knowledge, attitudes and behaviour. In particular, can these activities effectively assist the social learning processes and relationship building across different stakeholder groups considered necessary for just, effective and sustainable change? A series of tool demonstration workshops in the Philippines show-cased a variety of techniques that can be used by government, NGOs and other community groups to learn about, discuss, negotiate and plan for improved management of their tropical marine ecosystems. Drawing on workshop interactions, post-workshop interviews and observations, and the broader science communication literature, we can see some clear advantages of tool-based approaches when integrating different knowledge communities. The tools used were able to elicit Burns et al.'s (2003) 'awareness, enjoyment, interest, opinion-forming and understanding' (AEIOU mnemonic) of/in/about science from participants, a fundamental goal of IEC activities. On the other hand, the tendency for local managers to rely on external suppliers to implement such projects can undermine slower, locally initiated and less donor-friendly processes that may do more to address the root causes of reef degradation in the longer term. Poverty, underlying conflicts, inequality and entrenched attitudes cannot be eliminated through one-off workshops. However, science communication tools can provide stimulus and support for ongoing reef management activities from critical stakeholder groups.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1230, Sebel Kuranda

Challenging gender stereotype: women fishers ' protection & management of coral reefs - Philippines

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In 1998, female and male, fishers' organizations in Hinatuan Bay, Surigao del Sur, Phlippines established 7 fish sanctuaries (FS) covering a total of 414.7 hectares. The smallest fish sanctuary is 15 hectares and the largest 222 hectares. Out of the 7 FS, 6 are co managed by both male and female fishers and one FS was initiated by an all female fishers' organization. Involving women in coastal resource management involved a series of activities that highlighted women's role and contribution to the municipal fisheries sector. Both men and women have to recognize that women are fishers and should be participating and benefiting from all development efforts undertaken in the sector. After the PRA, gender sensitivity seminars and women orientation were conducted. Women were recruited to join the fishers' organization and given the opportunity to develop and improve their leadership skills. Separate women and men organizations were formed to give women the space to build their self-confidence. Realising that they perform 50 to 70% of the fisheries activities, women, hand in hand with men, joined the protection and management of the coral reefs in Hinatuan Bay, from site identification, generating policy support and day and night roving of the no take zones. Women were also trained in the conduct of biophysical monitoring and have been doing annual monitoring of the FS to improve management. They were also deputized as fish wardens, or bantay dagat, which previously was the domain of men.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1515, Sebel Kuranda

Stateless stakeholders: participation and governance in marine conservation

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The active inclusion of resource users into marine planning and decision-making processes is widely recognised as fundamental to achieving long term conservation objectives. Marine protected areas are increasingly planned as networked, ecologically inter-dependent systems representative of the diversity of marine habitats, in turn leading to an increase in the rate of designation and the number of protected areas worldwide. Concurrent with this, however, is a growing number of marine resource users who are not recognised as citizens by the countries where

they reside, reflecting a number of social, economic, historical and political factors. As the impacts of climate change on resource abundance begin to become apparent, the number of these “stateless stakeholders” is likely to increase. This paper will therefore outline current processes resulting in the condition of statelessness within maritime communities with a specific focus on south-east Asia. Using examples from Malaysia and Indonesia, the consequences of a lack of citizenship with respect to individual and community participation in marine resource management will be examined. These will demonstrate the need for a greater inclusivity and flexibility in marine resource management if policies are to deliver the required conservation outcomes.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1000, Sebel Kuranda

Barriers to livelihood security in a Bajo fishing community

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Marine resource dependent coastal populations throughout the developing world face increasing difficulties in pursuing viable livelihoods. Poverty and livelihood insecurities in fishing communities are strongly linked to their access to various assets or ‘capital types’ that enable livelihoods to be realised. Access in turn is influenced by a diversity of external and local (village level) political, social and economic factors. This paper examines barriers to accessing marine resources and livelihoods in the rural Bajo fishing community of Wuring Laut, Flores Island, eastern Indonesia. Using an ethnographic lens and an analysis of livelihood activities and strategies of a Bajo fishing community, it examines three key factors affecting access: 1) tenure; 2) social and cultural influences and practices 3) local governance of resources. The research results show that capacity of this fishing community to construct resilient and diverse livelihoods both within and beyond the local fishery sector is heavily constrained by difficulties in accessing financial capital, local physical capital such as fisheries markets and infrastructure; and inequitable distribution of profits from marine resources (as a result of poor position in the market chain). The results also demonstrate that social exclusion on the basis of ethnicity impacts access. The results from Wuring Laut are relevant to other coastal and maritime populations in Indonesia and Southeast Asia in respect to addressing broad goals around achieving sustainable fisheries in the face of increasing global pressure on resources and food and livelihood security for resource dependent populations.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1730, Sebel Kuranda

Historical, cultural and social perspectives on seafood consumption in China

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Since China is a leading market for a number of types of seafood, and much of this seafood is imported from other countries, Chinese consumption of seafood is an issue of vital importance to many of the world's fisheries. Focusing on luxury seafood, in particular béche-de-mer, shark fin and live reef fish, this paper firstly examines the links between Chinese consumption and species population trends in source countries. After a discussion of current efforts at conservation and management of these fisheries, the paper shows how the consumption of luxury seafood in contemporary China is intertwined with: broader historical trends, including the expansion of Southern Chinese cuisine; cultural beliefs and traditions, in particular surrounding elements of traditional Chinese medicine; and most importantly, notions of social status and conspicuous consumption linked to the development of the Chinese economy and social stratification. The paper points to the role of the historical, cultural and social processes that underlie Chinese luxury seafood consumption, and to the need for greater levels of action among various actors to address this consumption if sustainability is to be achieved.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1545, Sebel Kuranda

A new fisheries biology learning tool for the Pacific

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In this paper I report on trials of the impact of a DVD-based fisheries science learning tool on Solomon Islands secondary school students. The DVD explains in detail the biological and ecological mechanisms that link overharvesting to recruitment failure (and ultimately stock collapse) for a range of fished species of economic importance in the Pacific. The premise for developing the tool is that if a big enough proportion of the population clearly understands why it is that fishery production is ultimately controlled by human actions and not supernatural forces, it is far more likely that Pacific Islanders will come up with their own

governance innovations to effect successful management. While not ignoring overarching challenges such as escalating economic pressures and political disunity at multiple scales, the project aims to assess the extent to which improved scientific understandings of fishery biology and ecology can alter collective attitudes and behaviour toward coral reef fishery management challenges over the medium to long term.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1115, Sebel Kuranda

Human dimensions of coral reef fisheries across the US Pacific

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Over the past 20 years, it has become increasingly clear that coral reefs are some of the most threatened ecosystems in the world. It is now generally accepted that humans impact reefs in a variety of ways, from the direct effects of fishing to the indirect effects from climate change, and current research has begun to examine the intricacies of the relationships between anthropogenic factors and coral reef health. This presentation will describe current research efforts to synthesize long-term coral reef biophysical data with human dimensions data on islands and reefs throughout the U.S. Pacific. Some of the challenges inherent in this approach are not only how to characterize and compare these coral reef fisheries using the small amount of available data, but how to do so while also taking into consideration the larger social, political, and historical context in which these fisheries are embedded. While on one hand it is important to understand the overarching trends and commonalities across coral reef fisheries so that management strategies can address conservation concerns in a consistent manner, we must also be wary of falling into a 'one-size-fits-all' management approach that ignores humans' interactions with coral reef ecosystems and the institutions that manage them at a local scale. This presentation will describe these challenges as well as discuss how our interdisciplinary research team has approached integrating biophysical and social data to answer important questions about coral reef management across a broad scale.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1645, Sebel Kuranda

Gender and small-scale fishing practices in the central Philippines

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Understanding the gender dimensions of natural resource use has been found to have profound effects on the outcomes of conservation projects. Gleaning - the collection of animals from marine intertidal areas such as coral flats - is often characterized as a predominantly female-based activity. Gleaning is commonly overlooked in natural resource management, yet a thorough understanding of human pressure on the marine ecosystem requires the accounting of all resource extraction. The goal of our research was to 1) characterize small-scale fishing and gleaning by gender, and 2) examine the contribution of fishing and gleaning to food security, an important variable when assessing the effects on conservation and management measures. Our research was done in the Danajon Bankregion of the Central Philippines. We conducted 100 semi-structured interviews with women (n=50) and men (n=50) in two coastal communities. We found that most women glean (98%) and most men fish (92%), but that almost a quarter of women also fish (24%) and almost two-thirds of men also glean (62%). Though fishers report significantly higher catches than gleaners, catch from gleaning contributed an equivalent amount of marine protein to household food intake as fishing catches. My research demonstrates that gleaning is a common extraction method in this region and that gleaning is a significant contributor to family sustenance. To develop effective marine conservation strategies it is therefore important to consider how those strategies affect gleaning as well as other small-scale fishing methods.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1530, Sebel Kuranda

Conservation of our natural heritage: the Singapore experience

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Singapore is a highly urbanised city-state of approximately 700 km^2 with a population of almost 5 million. While large, contiguous natural habitats are uncommon in Singapore, there remains a large pool of biodiversity to be found in its four Nature Reserves, 20 Nature Areas, its numerous parks, and other pockets of naturally vegetated areas. Traditionally, conservation in Singapore focused on terrestrial flora and fauna. Recently, emphasis has shifted to the marine environment,

evidenced by the reversal of development works on a unique intertidal shore called Chek Jawa (Dec 2001), the legal protection of SungeiBuloh Wetland Reserve (mangrove and mudflat habitats) and Labrador Nature Reserve (coastal habitat) in 2002, and the adoption of a national biodiversity strategy (September 2009) and an integrated coastal management framework (November 2009). Singapore has also adopted the 'City in a Garden' concept; a 10-year plan that aims to not only heighten the natural infrastructure of the city but also to further engage and involve members of the public. The increasing trend of volunteerism, from various sectors of society, has made 'citizen-science' an important component in many biodiversity conservation projects, particularly in the marine biodiversity-rich areas. Some of the key outputs from these so-called '3P' (people, public and private) initiatives include confirmation of 12 species of seagrasses in Singapore (out of the Indo-Pacific total of 23), observations of new records of coral reef fish species, long term trends on the state of coral reefs in one of the world's busiest ports, and the initiation of a Comprehensive Marine Biodiversity Survey project.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1130, Sebel Kuranda

Filling critical socio-economic knowledge gaps in a changing climate

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Understanding and supporting resilience of reef-dependent people is as important for effective reef management as are efforts to build resilience of the ecosystem; resilient coral reefs need resilient communities and industries capable of responding to reef management directives. However, as the impacts of climate change manifest, we can expect that the relationship between people and the coral reef environment will alter, and the resilience of the socio-ecological system will be affected. Monitoring the relationship that people have with the resource (resource dependency) and their capacity to adapt to changes allows both the current status of industries and communities to be assessed, and provides a foundation upon which to monitor and support resilience. We present the Social and Economic Long Term Monitoring Program (SELTMP) recently established in the Great Barrier Reef. SELTMP assesses and monitors a range of characteristics, including resource dependency and adaptive capacity. Both secondary data sets and primary data sets are used to provide reef managers and other decision makers with an overview of the commercial fishing, marine tourism, shipping, mining, farming, and grazing industries of the region, as well as of the coastal communities, traditional owners and recreational users of the region. In this presentation we show the results of the first year of SELTMP and show how results are being used by reef managers to build resilience of the socio-ecological system of the Great Barrier Reef.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1145, Sebel Kuranda

Architectural and anthropological survey on coral buildings in Sinai Peninsula, Egypt

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We have started an architectural and anthropological survey of the traditional/modern coral building in the al-Tur al-Kilani site, located on the north side of the Bay of al-Tur in the southwestern part of the Sinai Peninsula, Egypt. Arabic historical sources mentioned that it was 1378/1379 A.D. (780A.H.) when the port city of al-Tur became important. This port was also used by Christian pilgrims on their way to the Monastery of Mt. Sinai and by Muslim pilgrims going to Mecca. In the excavation up to 1997 by the Japanese Islamic Archaeological Mission of the Middle Eastern Culture Center of Japan, three phases were identified; the first phase belongs to the 18th - 20th centuries; the second to the 16th -18th centuries; and the third to the 14th -16th centuries, in descending order. In 1985, the Japanese mission recorded 30 modern coral buildings standing in the eastern part of the site. According to an interview with a carpenter who built these coral buildings and had lived at the second/third floor of House No.31, he clearly mentioned that carpenters categorized corals into two groups: heavy ones and light ones. They have used heavy ones at lower parts and light ones at upper parts. They didn't use mangrove wood but date palm and acacia wood from locals. He also joined fishing boats going to collect corals around the Harghada islands, 50km from the al-Tur port, after returning from fishing to the south for several months.

22A Cultural, political & historical dimensions of coral reef management
P233

Integrating Traditional Ecological Knowledge (TEK) in the Kahalu'u Ahupua'a, Hawai`i

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Historically, Traditional Ecological Knowledge (TEK) has been disregarded because stakeholders and cultural practitioners often do not hold educational degrees in the topics or disciplines they speak of, nor have their observations been tested according to scientific protocols. Recently, there has been an expansion and integration of TEK and culture into science and management programs, providing an acceptance and recognition of Hawaiian values in relation to coral reef management. This movement will likely continue to influence the field of marine biology. A community based project at Kahalu´u Bay, Hawai´i in the ahupua´a (or land division) of Kahalu´u was developed to amass information about historical and contemporary coral reef resources, through interviews with the kapuna or elders who are knowledgeable about this region, and/or about information including cultural practices, legends, chants, or songs. The acquired TEK was used to formulate and test hypotheses concerning coral reef resources and demonstrate the important connectivity between culture and science, thus bridging the gap between both disciplines.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1145, Sebel Kuranda

Strengthening community leadership and conservation through effective communications

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Effective communication is often a determining factor in the success or failure of conservation efforts. When working across cultures, communications can be even more complex. In response, SeaWeb has piloted an innovative initiative to advance conservation in the region called the Community Educators Network (CEN).The CEN initiative provides traditional community leaders with science training and communication tools to present conservation issues and facilitate discussion in a village setting. A key element is working with community leaders to draw upon traditional ecological knowledge and traditions to communicate conservation in compelling ways. The powerful marriage between science and culture in turn creates relevancy and broad consensus for management actions. CEN also reaches out to marginalized village groups such as women and youth. In partnership with on the ground organizations, this initiative is being piloted in Kubulau District, Vanua Levu, Fiji, and in Manus Province, Papua New Guinea. We present the CEN methodology and discuss outcomes, including increased community enthusiasm for conservation, increased community organization and action, and potential CEN applications for other areas.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1215, Sebel Kuranda

Coral reefs in museum exhibitions

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Coral reefs in museum exhibitions often come as flatware, posters with large flashy photographs and video screens. Some pale scleractinian skeletons and fish replicas provide exotic decoration, often with mysterious Latin labels rather than instructive context information. Complex 3D-installations demonstrating the diverse relations of various reef dwellers are costly and laborious. Necessary efforts are usually only worthwhile for permanent exhibitions with high visitor frequencies and no need for transportation. However, to allow an impressive reef experience for non-scuba-diving audiences 1:1 scale exhibits provide diverse options to demonstrate reef specific organism interactions, including: reef building and erosion, cleaning symbiosis, predator-prey relations, behavioral patterns like courtship and camouflage. Thirty years ago the German Oceanographic Museum built a coral reef section model four and a half meters high as the outcome of two coral reef expeditions to the Red Sea. Recently, the model was completely rebuilt. Situated in a 13th century monastery church hall, the glass case was reconstructed with up to 6-meter glass-panes, allowing spectacular perspectives of the model at three different levels, including overlying open water space. Ground and first floor level views were fitted with an audiovisual sound installation: 200 individual light sources allow the diurnal simulation of changing light conditions in the reef, highlighting the activities of various reef organisms. A narrator guides the visitors along the plots of different acting taxa, explaining functional processes with the protagonists individually highlighted. The poster presents the history, concept and planning of this master-exhibit, provides insight in workshop processes and gives examples of the educational content.

22A Cultural, political & historical dimensions of coral reef management
P234

Strengthening coastal governance by harmonising traditional and 'western' multi-sectoral management

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The Pacific is demonstrating some of the most promising models of strengthening governance and enabling mechanisms at community, provincial, national and regional level for long term sustainability in coastal resource management and coral reef management. In the Solomon Islands strengthening provincial level governance in natural resource management has been demonstrated in the Central Islands Province through establishment of a multi-sectoral arrangement to improve coastal resource management and governance. At the national level, networks such as the Solomon Island Locally Managed Marine Areas Network (SILMMA) and Fiji Locally Managed Marine Areas (FLMMA) Network have been established to integrate and improve coral reef management and monitoring. The multi-sectoral approach includes NGOs, government, local knowledge & practices, private sector and science towards improving practices, governance and resource allocation. At the regional level there are regional coordination mechanisms such as the Pacific Islands Roundtable for Nature Conservation (PIRT); this is a coalition of nature conservation and development organizations, governments, inter-governmental, donor agencies and community groups created to increase effective conservation action in the Pacific Islands Region. The Asia-Pacific Locally Managed Marine Areas Network supports communities and governments towards Best Management Practices in coral reef conservation through improving good natural resource management practices and building on traditional management approaches and applied science.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1015, Sebel Kuranda

Social factors affecting shark conservation in Belize: a case study

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Sharks play an important ecological role in the structure and resilience of coral reefs. Research indicates a worldwide decline of sharks at an unprecedented rate, yet, sharks are often not protected. There is a need to better understand the communities that rely directly on marine natural resources and to consider them in marine policies. In this paper, we present the results of an exploratory study of shark stakeholders in Belize, their relative importance, their interactions and influence on shark outcomes. Working within a grounded theory paradigm, using case study and stakeholder analysis we conducted 39 interviews and 3 focus groups with stakeholders in 2011. We limited our study to Southern Belize, in coastal communities where tourism and fishing are important and diverse stakeholder groups operate. Participants were selected purposively, from six stakeholder categories: (1) government, (2) fishermen (3) restaurants, (4) NGOs, (5) tourism and (6) academics and scientists. Results revealed that Belizeans did not significantly fish and consume sharks; Mexicans, Guatemalans and Hondurans eat shark, and fish for shark within Belize waters, especially during Lent. Various conflicts between and within stakeholder groups were identified. Differences in the perceptions of stakeholders can challenge policy-formation and ultimately the conservation of sharks. Shark conservation on the Mesoamerican Barrier Reef needs to be better understood at a regional level, including stakeholders from Belize, Mexico, Guatemala and Honduras.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1415, Sebel Kuranda

Use of coral communities as tourist resources in Kushimoto, Japan

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One of the best ways to improve economic potential in Japan is to capitalize on the abundant tourist attractions found around the country. One of the most notable natural resources for tourism is the coral communities at Kushimoto, in the Wakayama Prefecture in the south west of Honshu. This is the northernmost extent of coral reefs in Japan and was designated as protected wetlands by the 2005 Ramsar Convention to conserve its numerous species of coral and waterfowl. Since 2009, the author has investigated tourists' tendency in making inquiries about coral conservation and the economic trends in Kushimoto to test the following hypotheses; 1. The Ramsar Convention has strongly and efficiently influenced Kushimoto in its original intention (to conserve corals and improve the region's economy), however the treaty currently has different effects in the region. 2. Most tourist think that corals should be conserved and they should pay for conservational efforts, however there are many interfering circumstances, including political aspects that deter such efforts. The author will explain the

current conditions in coral conservation and associated economic efficiency in Japan, and discuss the overall perspectives including existing issues.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1215, Sebel Kuranda

Challenges for creating a fishing refuge in the Mexican Caribbean

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Local social, economic and cultural elements play a key role in defining and implementing coral reef protection measures. The challenge of integrating these factors into the Mexican legal framework and internationally driven novel initiatives for marine ecosystem management in the Caribbean, will be presented. A local NGO has facilitated a process over the past five years to create a marine protected area 'from the bottom up'. The results from three years of economic activities in marine tourism will be presented, along with a brief description of the main legal and social issues for success.

22A Cultural, political & historical dimensions of coral reef management
P235

Territoriality among small-scale fishers and its implication for coastal resource management

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This paper examines the informal territoriality over fishing grounds claimed by local small-scale fishers in southeastern Cebu Island, the Philippines. In tropical waters around coral reefs where the natural environment and human activities are highly complex, models based on self-sustaining site-specific territorial arrangements that are embedded in local cultural and socio-economic contexts have been proposed as one key alternative approach to coastal resource management. There are only very limited studies on such arrangements in the Philippine context, as it is generally considered that the open access principle is robustly practiced and such localised arrangements are insignificant. This paper claims, however, that informal territoriality over local waters is in fact operated and rationalised by small-scale fishers and shows how it is related to the formal fisheries and coastal resource management framework. Drawing upon cases of territorial claims in bottom-set gillnet fishing in coastal waters and multiple hook-and-line fishing in offshore waters, this paper demonstrates that longstanding continuity, localness, and social status are key concepts for fishers in justifying their claims. The paper argues that the fishers' territoriality emerged out of a necessity to protect their livelihoods, through avoiding risks and preserving the resources for their own use rather than that of outsiders. It contends that in-depth research into local territoriality with multifaceted approaches to the social and political environment, is necessary for designing meaningful and realistic forms of co-management.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1030, Sebel Kuranda

Integrating knowledge systems and methodologies

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Integrating indigenous and western scientific knowledge systems is becoming more prevalent as we move into an era supporting diversity in resource management. Utilizing both systems creates a firm foundation in truly understanding ecological environments, which contributes to the better protection of our natural environment. The 'Integrating Knowledge Systems and Methodologies' project has taking the next step in integration through understanding the methodology of gathering information within knowledge systems and not simply replicating the knowledge itself. Environmental knowledge is very specific to time and place and we can continue to apply these processes to address the questions of today in the location of our research. Relationships also play an important role in data collection and influence the types of questions we ask and how we go about answering them. Through integrating our worlds, we also integrate our relationship with the environment, which ultimately affects how we interact with it. Over the past two years, we have focused on different ways to collect data based on a wide range of relationships; scientist, cultural practitioners, managers, educators, fishermen, etc. These processes helped to provide protocols that satisfy our needs and relationships as scientists, community members, cultural practitioners, and environmental managers. More importantly, it helped us to understand the environment of Hawai`i as contemporary extensions of our ancestor's thoughts and thus our understanding will include how we can sustainably interact with it.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1200, Sebel Kuranda

Social and economic drivers of transboundary environmental degradation in the Arafura -Timor Seas

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The Arafura Timor Seas (ATS) encompasses waters under the jurisdiction of four countries: Indonesia, Timor-Leste, Australia and Papua New Guinea. As an ethnically and linguistically diverse region with stark economic, social and governance gradients, the seas provide livelihoods for millions of people in the region, making a significant contribution to food security and incomes for both coastal communities and also populations in the export market countries to the north. However, biodiversity and the wellbeing of human populations are at risk from severe environmental degradation, in particular from depletion and loss of fisheries resources and biodiversity; habitat modification, degradation and loss; and pollution and impacts of climate change. This paper examines the social, cultural, economic, policy and conservation drivers of marine and coastal activity and impacts from environmental degradation in the ATS region. It explores the interconnected drivers and processes operating at the global, national, regional and local scales, which are often difficult to separate. The paper highlights the challenges in addressing indirect and direct drivers for the future sustainable management and local livelihoods in a socially and economically diverse region.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1715, Sebel Kuranda

Integrating culture and conservation: experiences from a locally managed marine area in Indonesia

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Effective long-term management of coral reefs in remote archipelagos of Eastern Indonesia requires far more than technical ecological know-how. An integral understanding of the dynamics of local culture, political sphere and social networks is of utmost importance. Local artisanal fishing communities must stand to play an important role in managing their livelihood source and living environment. This research examines in detail, the establishment of a locally managed marine area, in order to provide fresh insights into how collaborations across institutional interfaces can be reinforced by acknowledging local cultural and political context. The research draws on an in-depth case-study of the Tanimbar Kei island community in the Kei islands of Maluku Province, located in Eastern Indonesia. Through collaborating with a local conservation NGO, the community has held onto its traditional marine management schemes to ensure that conservation targets are not simply prioritised at the expense of local autonomy over the environment. The case study provides an empirical foundation to expose on-the-ground complexities in culture and local politics, and how these dynamics can support and/or undermine partnerships between resource users and conservation oriented organizations. Through an inductive ethnographic approach the study uncovers cultural linkages that exist between local resource users and their immediate marine environment, and how these are continuously being shaped and communicated. The research furthermore explores how such small-scale participatory conservation arrangements can be linked to conservation initiatives beyond the community, and in doing so function within multiple-scale conservation governance frameworks.

22A Cultural, political & historical dimensions of coral reef management
Thursday 12 July, 1630, Sebel Kuranda

Conserving global marine biodiversity: implications for Brazilian public policy

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Marine issues often cross political barriers and are thus relevant to the study of international relations. This study aims to characterize the conservation of marine biodiversity as a global political problem within the scope of the Convention on Biological Diversity (CBD), and discuss the implications for environmental public policies in Brazil, with special focus on reef environments. Official documents and legislation were analyzed and key actors from several sectors were interviewed (government agencies, nongovernmental organizations, academia, United Nations, and business community). Among the main results, we describe difficulties related to domestic implementation of the convention, including conflict of interests among different

governmental sectors. We suggest that the CBD has promoted behavioral political change, stimulated academic production related to marine biodiversity, and helped raise the issue's domestic visibility. Overall, the convention has been most effective in terms of its problem-solving capacity and did not perform so well regarding political context; the worst outcomes were due to the problem's structure.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1200, Sebel Kuranda

Local experimentation and negotiation in Lau Lagoon, Solomon Islands

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To communities in Lau lagoon, Malaita province, Solomon Islands, mangroves are important because they provide: food in the form of the much valued koa; income from koa and firewood; fuel and building materials; shelter from wind and waves; and waste disposal. Lau people also recognise that mangroves provide essential habitat for fish, shells, crab and other wildlife. Nationally, mangroves are valued from both a fisheries and climate change perspective. Ecosystem-based fisheries management, to include mangroves, is an emerging interest in the Solomon Islands as a result of the Coral Triangle Initiative. Mangrove rehabilitation and management is also identified as a critical adaptation strategy in the National Adaptation Plan of Action. But, historically mangroves are not included in customary tenure over land and sea. We present on emerging structures and processes of mangrove governance in five communities in Lau lagoon. We discuss people's perceptions of environmental change in their lagoon, relating the different viewpoints of men, women and youths. We showcase examples of local experimentation on mangrove replanting. And we critically explore the establishment of property and use rights around existing and new mangrove habitat. We couch our presentation within the national policy drive in the Solomon Islands for integrated coastal management through the community-based management model, to reflect on the potential for integrating biodiversity conservation, fisheries management, and climate change adaptation in single focal sites.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1445, Sebel Kuranda

Social and cultural attributes of effective marine adaptive co-management systems.

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Adaptive co-management (ACM) is an emerging approach to marine management, which aims to create cross-scale, collaborative management strategies, that foster resilience in social-ecological systems However, the governance arrangements, social mechanisms and processes which create and sustain successful adaptive co-management are still under-investigated and often misunderstood. There is no 'one-size fits all' solution, particularly in different governance systems and socio-political contexts. Therefore, understanding the successes and failures in marine governance systems is a first step in improving their adaptive capacity to secure ecosystems services and build resilient livelihoods in the face of uncertainty and rapid change. This study examines the governance systems, and the socio-cultural and adaptive co-management features and attributes, using hand collectable fisheries of Fiji and Torres Strait Islands of northern Australia as case studies. We present the outcomes of this study in this paper and discuss the gaps in effective marine co-management, the desired future of co-management arrangements and management strategies that allow the evolution of ACM based on blending together local and western science ecological knowledge. The study emphasizes the significance of community involvement and stewardship that can change patterns of interactions among key actors and allow for new adaptive forms of co-management and governance to emerge in response to changes in marine management. It illustrates that enabling legislation or other social bounds are essential, but not sufficient for shifting governance toward adaptive co-management of complex marine ecosystems.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1230, Sebel Kuranda

Socio-economic value of the shark-diving for small Pacific island nations

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The recent declarations of bans on shark fishing and trade of shark products, represent a step forward in global shark conservation efforts. In developed nations, this trend has been supported by recognition of the ecological importance of sharks as apex predators for marine systems and the impacts of fishing on their populations worldwide. In contrast, the recent implementation of nationwide fishing bans by island nations across the Indo-Pacific and Caribbean has been primarily motivated by the recognition of the high economic value of reef sharks as a non-consumptive resource, mainly for the shark-diving industry. Here we compare the economic scenarios of the shark-diving industry in two Pacific island nations that rely heavily on tourism, describing the financial benefits of shark conservation to the local economy, community and government. In Palau, a relatively small nation, shark diving generates 8% of the Gross Domestic Product of the country, USD1.2 million in salaries and USD1.5 million in taxes annually. This highlights the importance of the shark-diving industry to the economy of the country. The relative importance of the shark-diving industry to the national economy of Fiji is not as pronounced, primarily due to its much bigger economy. On a local scale however, shark-diving operations across the country generate annual revenues of up to USD187,000 in salaries and USD80,300 in levy to local villages, which would otherwise benefit marginally from ecotourism. These socio-economic benefits promote the active support to shark conservation by local communities, which is further legitimated and enforced by their traditional ownership of fishing grounds.

22A Cultural, political & historical dimensions of coral reef management
Friday 13 July, 1430, Sebel Kuranda

22C Management of coral reefs in regions of high biocultural diversity

Social, cultural and financial evaluation of managing marine resources

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The management of coral reefs, located where rich biodiversity interact with rich cultural diversity, poses many challenges due to the difficulty of meeting both biological and cultural objectives. We propose a conceptual framework based on a case study linked to the harvest of turtles and dugongs in the coral reef environment of the Torres Strait region of north-east Australia. Our framework provides a stepwise process for integrating peoples' cultural values into the protection of their marine resources by: (1) identifying and quantifying the different values of local community members towards their marine resources; (2) using those values to measure the social, cultural and financial impacts of hypothetical conservation management strategies from the perspectives of local stakeholders; and (3) identifying management strategies likely to be most acceptable and enforceable. Our framework uses both qualitative and quantitative techniques including interviews, cognitive mapping analysis, ratings, market and household expenditure survey, household questionnaires and network analysis. Our approach can be applied to other coral reef conservation problems in rich biocultural areas to ensure biodiversity conservation while reflecting local stakeholders' cultural values. Conservation practitioners are realising that the conservation of coral reefs needs to be context-specific and suited to the culture of the people sharing this environment. Therefore, our conceptual approach is timely, and should be of interest to those working towards an integrated biological and cultural approach to coral reef conservation.

22C Management of coral reefs in regions of high biocultural diversity
Thursday 12 July, 1030, Sebel Kuranda

Incorporating the knowledge of traditional peoples in qualitative risk assessments

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Systematic approaches to expert elicitation are increasingly used to assess the relative impact of multiple threats in data-poor environments. The approaches are generally limited to collecting the expert opinion of scientists and managers because social and linguistic barriers prevent them from being used in traditional communities. It is essential to capture the knowledge of traditional peoples because: (1) the knowledge and practices of traditional peoples are vital for the effective management and conservation of habitats and species; and (2) the outcomes of risk assessments are more acceptable to communities when they are included in the process. We developed a survey tool to bring together expert opinion on the relative impact of human threats in Torres Strait, Australia. The survey tool adhered to cultural protocols as it was specifically designed to capture the knowledge of Traditional Owners and community members, as well as government officers, commercial fishers and scientists. We used a qualitative risk assessment approach to measure the

vulnerability of twelve marine habitats to sixteen human threats by directing survey participants to consider issues of resistance, recovery and exposure. The outputs of the survey provided quantitative information on the relative impact of human threats on marine habitats and the data necessary for the strategic deployment of limited conservation resources at both a community and Torres Strait scale.

22C Management of coral reefs in regions of high biocultural diversity
Thursday 12 July, 0930, Sebel Kuranda

Are we succeeding? Monitoring and evaluation strategies for marine species management

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Many of the world's marine wildlife populations are threatened by anthropogenic processes and many species are listed as threatened by State, National and International legislation. Consequently, marine wildlife conservation projects have gained momentum and they now exist in dozens of countries throughout the world. Rarely however, are the benchmarks for success, or necessary evaluation tools explored and implemented to determine project or program success. Defining 'success' and how it is assessed are two of the fundamental issues that often lead to project and program evaluation being placed in the 'too hard basket'. There are endless criteria, and combinations of criteria that one could use to evaluate success (e.g. biological scales, social scales, and economic scales). In this presentation I: (1) apply 'program logic' and 'program evaluation' to a large (~$1million) turtle and dugong conservation project in north Queensland, Australia to serve as an example of project monitoring and evaluation processes;(2) determine research impact; and (3) provide examples of evaluation tools that can easily be incorporated into project or project plans to judge short term and long term success. Our research data indicated that we increased knowledge, attitudes and aspiration of Indigenous participants and Indigenous government agencies, and that these increases have had positive conservation value.

22C Management of coral reefs in regions of high biocultural diversity
Thursday 12 July, 1040, Sebel Kuranda

Factors influencing success of traditional management of Fiji reef fisheries

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The total biomass of coral reef fish at near-pristine and well-managed sites in Fiji rivals the highest values recorded anywhere in the Pacific. Here we present biophysical and socioeconomic factors that contribute to the preservation of reef fish populations, as well as factors that contribute to their swift declines. Traditional management has successfully sustained extraordinary reef fish biomass within the Namena Marine Reserve (Kubulau District, Bua: 1743.8 -247.3 kg/ha) and Daveta Tabu (Totoya Island, Lau: 4711.8 - 1452.1 kg/ha). We attribute this success to physical inaccessibility, large distance from commercial centres, steep reef slopes, high currents, large area under management and strong and long-term respect for taboos placed on fishing at these sites. However, a case study of Cakaulevu Tabu (Kia Island, Macuata) indicates that traditional management practices might not be robust in the face of new economic opportunities, for example, when direct links are made to markets and middlemen operating for seafood export companies. An intensive harvest of this community-managed protected area, initiated as a fundraiser, resulted in a 45% removal of total reef fish biomass (initially 6409.0 - 1178.2kg/ha) after 4 weeks, with only 83% of original biomass remaining one year later. Following high intensity fishing, primary targeted species (e.g. *Naso unicornis*, *Caranx melampygus*) were largely extirpated and reefs were numerically dominated by small, roving grazers (e.g. *Ctenochaetus striatus*, *Chlororus sordidus*) with low residual biomass. We discuss research and policy priorities to improve the sustainability of traditional management in Fiji.

22C Management of coral reefs in regions of high biocultural diversity
Thursday 12 July, 0945, Sebel Kuranda

Social, economic and political impacts on coral reef growth

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Sasisen' is a traditional marine management method applied by coastal communities throughout eastern Indonesia. Local and migrant fishermen commonly applied bomb fishing techniques using abandoned World War II explosives. In response to local concerns of continuing coral degradation, the Indonesia Locally-Managed Marine Area Network (ILMMA) started assisting coastal communities in developing local regulations on marine management by building on existing sasisen institutions. Through these collaborations, several communities have formulated village-

level regulations on marine resource management. With further political recognition these communities have started managing and protecting their immediate marine environment with legitimate authority. This study explores findings in two islands: Meos Mangguandi and Meos Auki, in the Padaido Islands, Biak, Papua, Indonesia. Fieldwork was conducted from March to April 2011 to collate findings from the last ten years and to show how the development of social, economic, and political capital in these communities has impacted live coral growth. This improvement is correlated with a significant increase in Meos Mangguandi live coral cover from 2000 to 2010, from 43% to 59%. However, in Meos Auki it decreased from 27% to 11% from 2000 to 2005, but increased to 24% by 2010. The results show that: (1) social, economic, and political conditions at the community level have significant impact on coral cover growth; and (2) the application of sasisen practices forms an effective tool to engage resource users in sustainable conservation and improvement in ecological health.

22C Management of coral reefs in regions of high biocultural diversity
Thursday 12 July, 1000, Sebel Kuranda

Traditional reef fisheries management practices of the South Sinai Bedouin

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Having lived for centuries under the harsh conditions of the Sinai desert, the Bedouin have developed a sophisticated understanding of their natural environment and have developed strict laws and traditions governing the use of its resources. However, Bedouin fishing practices and traditional rights to coastal resources have been restricted over recent years. During the Israeli occupation (1967-1979), large-scale commercial fishing by Bedouin fishermen was prohibited and individual permits were required. In more recent times, tourism and National Park development along the coastline, particularly in Sharm el Sheikh, has largely limited Bedouin access to fishery resources. Tourism has also brought social complications including prostitution, sexual relations and intermarriage with foreigners, drug dealing and addiction, and materialism. Until the early 1980s, 80% of coastal Bedouin communities relied on fishing as their main source of livelihood; fish was not only used for household consumption, but was also dried and traded with inland Bedouin from Saint Katherine and the surrounding area. Bedouin are still permitted to fish within the National Parks, using traditional gears from the shore and, although these concessions have contributed to the Bedouin community's acceptance of protected areas, there still remain substantial opportunities to improve the management of coastal resources. If studied carefully and extensively, incorporating traditional management practices into National Park policy may provide an opportunity to ensure tangible and effective inclusion of Bedouin stakeholders and could provide useful ideas to more effectively manage the coastline.

22C Management of coral reefs in regions of high biocultural diversity
Thursday 12 July, 1015, Sebel Kuranda

Successful community adaptive management approaches for maintaining marine biocultural diversity.

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The Locally-Managed Marine Area (LMMA) Network works to support local communities in effectively managing marine resources in areas of high bio-cultural diversity within the Indo-Pacific region. Active in seven countries and encompassing roughly 400 community-led locally managed marine areas, the Network strives to develop and promote appropriate, user-friendly approaches for resource-managing communities to address threats to resources and other biodiversity on which they depend. The Network structure has a small central staff who manage regional Network assistance to country networks, and in-country coordinators, who plan and implement local activities supporting independent country network programs and partner organizations. A hallmark of LMMA Network is promotion of community-based adaptive management (CBAM). Intended to be simple and flexible enough for community use and diverse cultural settings, CBAM is a management cycle where local stakeholders lead the development of a management plan, implement, check on, and then revise the plan (if necessary) - reiterating and adding appropriate steps where necessary. This process encourages the use and incorporation of traditional knowledge, local language, and cultural practices into the management planning process. Thus, customary practices are supported and reinforced, rather than being relegated, as may occur within other arrangements. The Network provides support and a framework for country and regional level networking so that exchange of lessons and principles garnered from the variety of local experiences can be enhanced. Examples of these cases will be presented, as well as discussion of key elements of the Network which promote the maintenance of biocultural diversity.

22C Management of coral reefs in regions of high biocultural diversity
Thursday 12 July, 1035, Sebel Kuranda

Embracing invasive species management: lionfish control along the Mesoamerican Reef

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Among the many threats that Caribbean reefs face, one of the more pugnacious is the invasive lionfish (*Pterois volitans*). Along the Mesoamerican Reef, lionfish have become a common sight, so much so that it is difficult to dive without seeing multiple lionfish. The broad diet of lionfish and their voracious appetite, threaten Caribbean coral reef ecosystem structure and health. The Coral Reef Alliance began working with partners in Mexico, Belize, and Honduras to suppress lionfish abundance at local scales. We leverage the marine tourism industry to raise awareness and educate both tourists and local communities about the threat lionfish pose to local economies. In Belize we sponsor lionfish tournaments, where over the course of 3 tournaments 1,795 lionfish were permanently removed from the reef. Where this effort has limited capacity for suppressing populations over large temporal and spatial scales, the tourism and seafood industries hold great potential for influencing fisheries targets. While the concept of promoting and serving lionfish in restaurants is not new, we have made substantial gains in Honduras and Mexico where, with partners we are seeing restaurants begin to showcase lionfish cuisine. We have also sponsored the development of a lionfish cookbook with some recipes published nationally. We are also establishing a 'lionfish safari' in Cozumel to promote the removal of lionfish from specific reefs. Through the use of techniques such as these and strategically focusing efforts on reefs that are otherwise healthy we may be able to suppress lionfish populations locally to maintain vibrant coral reefs.

22C Management of coral reefs in regions of high biocultural diversity
P236

22D Economic valuation & market-based conservation

Balancing economic needs with ecosystem services in Solomon Island communities

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Coral reef and mangrove ecosystems provide Solomon Islands rural coastal communities with valuable goods and services integral to their livelihoods. Traditionally, corals are an important resource for betel nut lime and building seawalls; and mangroves provide firewood, building materials and food. In most areas of Solomon Islands, marine resources are in good condition, however high population growth and exposure to the global economy is increasing the pressure on these resources. The purpose of this research was to assess the use and economic value of coral reefs and mangroves to provide the Solomon Islands government, and ultimately the communities that depend on these resources, with a better understanding of the value of their resources and potential for sustainable financing options. The outcomes from this work demonstrate in the current economic reality of Solomon Islands, in places where resources are over-harvested, the value received by communities for exploiting coral reef and mangroves for certain 'goods' is well below the 'ecosystem services' value that they provide. By giving rural communities a direct economic stake in the protection and sustainable use of their resources, sustainable financing mechanisms can provide a realistic solution to improve conservation and rural livelihoods.

22D Economic valuation & market-based conservation
Thursday 12 July, 1630, Hall C

The protective value of coral reefs in calculating insurance premiums

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Coral reefs protect coastlines by causing offshore waves to break; therefore, they dissipate wave energy that would otherwise propagate shoreward. This protective function provides a benefit to coastal homes, buildings and infrastructure by minimising erosion and the direct physical impacts of intense wave activity. The reduction in wave energy provided by a coral reef is directly related to the depth of the reef crest, with larger more energetic waves propagating through deeper water. This generates concern that the protective capacity of coral reefs will be diminished by climate change, through a combination of rising sea levels and eroding reefs in response to acidification and warming. Theoretically, this protective function served by coral reefs could be taken into account by insurance companies when determining insurance premiums. When setting premiums, insurance companies calculate the cost to repair or replace property following the occurrence of an insured event. In

some instances, calculations also involve a consideration of any features of property that reduce the risk of an insured event occurring. Insurance companies could take into account the protective function served by coral reefs when setting insurance premiums for events including storm, storm surge and erosion. This paper evaluates the current role of reefs as a source of coastal protection for the insurance industry and provides evidence to include the value of this ecosystem service in the determination of future premiums. Incorporating a financial benefit to the ecosystem services provided by intact coral reefs will provide incentive for coastal conservation.

22D Economic valuation & market-based conservation
Thursday 12 July, 1645, Hall C

Untapped millions: utilizing impact investments to improve ocean health

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Impact investing has the potential to significantly scale-up marine conservation finance. Philanthropic giving and government support will always be necessary but will never be enough to finance global, lasting ocean health solutions, even when innovative approaches are taken to secure these funds. The future of marine conservation finance will revolve around balanced portfolios where government and philanthropic dollars are complimented and outnumbered by green capital. Impact investments, or capital that is invested with the explicit expectation of economic, cultural, and environmental returns, is predicted to grow to a $500 million industry in the next decade. Terrestrial conservation and social development programs have been accessing this capital for decades, but successful impact investments in the marine conservation field have been limited and it is time for our community to move forward. Green capital and business leaders are largely available, but we are limited by bridgers - marine conservation leaders that can connect ocean health goals, social capital, and entrepreneurs. The Hawaii Fish Trust, a program of Conservation International, is testing ocean impact investment solutions on the ground.

22D Economic valuation & market-based conservation
Thursday 12 July, 1215, Hall C

Coastal capital: taking stock of coral reef valuations in five Caribbean countries

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Across the Caribbean region there has been a vocalized demand for estimates of the value of coral reef goods and services to local economies. In 2005, the World Resources Institute initiated the Coastal Capital project series to develop a coral reef valuation methodology and apply it, to develop estimates of coral reef values in order to influence better stewardship of coastal resources. To date, WRI and its local partners have conducted economic valuation studies of coral reefs at national and sub-national levels in five countries: Trinidad and Tobago, St. Lucia, Belize, the Dominican Republic and Jamaica. These valuations have focused on the economic contribution of coral reef-associated fisheries, tourism and shoreline protection services. Although the original intention of the Coastal Capital project was to develop and apply a standardized coral reef valuation methodology in countries across the Caribbean, our methodology and approach has varied, adapting to differing circumstances in each country. The result is a set of value estimates, which highlight important goods and services provided by reefs in each country, but which are not comparable across countries. We would like to share a summary of our approaches, results, impact, and lessons learned over the five-country implementation. This will lead into discussion about what scale and which types of values seem most useful for providing incentives for better management of coastal ecosystems.

22D Economic valuation & market-based conservation
Thursday 12 July, 1530, Hall C

Comparing two value chains in the Coral Triangle

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Live reef-fish for food (LRF) and live corals for aquaria are two high profile commodities from the Coral Triangle (CT) that are worth billions of dollars in trade but are sustained by small fishing communities dependent on coral reefs for a variety of purposes. Trade in LRF is 30,000 tonnes per year concentrated in Hong Kong and South China, and is worth anywhere from US$400 million to US$1billion. Leopard coral grouper (*Plectropomus* spp.) currently sells at roughly US$100 wholesale in Hong Kong, five times the price of the same fish if dead, and three times the value of the ex-vessel or farmgate price in the Philippines. The six countries of the CT contribute to more than

80% of the global coral trade. In the Solomon islands, corals are exported as live specimens for aquaria or dead for the curio trade. Total gross export value of the marine aquarium trade, dead corals, and other associates is valued at about US$700,000. In the Solomons, the price at which corals are bought from village collectors have remained stable at around US$0.25 to US$0.50, compared to the retail price which hovered in the range of US$35 to US$135. We used value chain analysis to characterize the participants and their behaviour in the LRF and coral export trade in the Philippines and Solomon Islands respectively, assess transmission of pricing, transparency of information, and lastly, determine value adding activities and associated costs for each level of the market chain to assess equitable distribution of benefits.

22D Economic valuation & market-based conservation
Thursday 12 July, 1500, Hall C

Loss of economic value due to coral bleaching in South East Asia

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In 2010, a rise in sea water temperature off Thailand, Indonesia, and Malaysia resulted in substantial coral bleaching. An ecological and economic survey was undertaken to determine the extent of this bleaching and also the economic implications, particularly for scuba divers. As part of the survey, a choice experiment was undertaken to determine the loss in non-market economic value to divers as a result of coral bleaching. In this paper, we present the results of this analysis, and implications for ongoing monitoring and management of the reefs.

22D Economic valuation & market-based conservation
Thursday 12 July, 1230, Hall C

Using market-based conservation for alternative livelihoods in Eastern Indonesia

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Developing sustainable alternatives to fishing in tropical coastal communities that have a heavy dependency on coastal resources is a priority in areas where heavy fishing effort and destructive practices are undermining the productivity of fish stocks and the ability of the system to provide benefits into the future. In Indonesia, 60% of coastal communities are directly dependent on coral reefs and associated ecosystems for food and livelihoods. Poverty, open access institutions, and a lack of alternatives to absorb excess labor, can lead to overexploitation of reef-based fisheries, declining catch per unit effort, and the loss of biodiversity and other essential services. This paper describes a series of nature-based, eco-enterprise models designed to provide commercially viable business opportunities to communities with a heavy dependency on coral reefs. The ability of these eco- enterprises to generate revenue streams to communities from intact coral reefs, and provide needed incentives and financing for conservation, will be tested in remote communities in Eastern Indonesia under a third phase of the Coral Reef Rehabilitation and Management Program (COREMAPIII).

22D Economic valuation & market-based conservation
Thursday 12 July, 1245, Hall C

Key ecosystem values and their implications for fisheries management

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People's values, and the structural features of their social setting, influences behaviour. However, how these interact to influence policy has not been explicitly examined. Using a case study of coral reef artisanal fishers in Seychelles, we investigate how incorporating people's values, and their contextual characteristics, influences the outcome of two policy approaches; decentralised and incentive based. We used focus groups, individual questionnaires and stated preference valuations to distinguish, rank and estimate ecosystem goods and services associated with the fishery. Information on 16 contextual characteristics, thought to influence the ability of communities to self-organise and collectively manage their resources, was also collected. A diversity of values was associated with the fishery. Cultural and commercial values, followed by conservation values, were of greatest importance. Individuals who prioritised cultural values were likely to also prioritise conservation values. Different individuals prioritised commercial values. Individuals with large cultural values reflected characteristics thought to enable cooperation and trust; lending support for decentralised approaches.

However, the demand for commercial values increased with decreasing income; creating distributional implications associated with incentive based approaches. Consequently, a tax would work differently to a subsidy, with only a subsidy likely to be effective. By achieving successes in some of the fishery, managers can buy time to invest in long term plans to develop alternative livelihoods, build trust, cooperation and support where management is most needed.

22D Economic valuation & market-based conservation
Thursday 12 July, 1130, Hall C

Ecomarkets for conservation and sustainable development in the coastal zone

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Long term stewardship and conservation efforts often suffer when communities rely exclusively on direct resource extraction from natural systems for their livelihoods. This is frequently the case for coastal inhabitants of developing countries. Conventional conservation strategies that attempt to protect the non-market values of an ecosystem by excluding human use usually do so at the expense of realizing the economic benefits of the market, for example by banning logging, fishing, mining, hunting, or other activities. The loss of these revenue-generating activities can result in unacceptably high economic and social losses. To offset these losses, new kinds of ecomarkets can be created to generate revenue from sustainable activities in the coastal zone that maintain ecosystem structure and function, thus allowing coastal communities to stop relying exclusively on natural resource extraction. A group of conservationists and scientists are working to develop ecomarkets for suites of ecosystem services off the coast of Mexico. Examples could include auctions of dive tourism privileges, payments for ecosystem services, and carbon credits. Development of innovative financial instruments, such as bonds, trusts and ecosecurities may also be useful for providing capital in the short term based on anticipated long-run benefits of conservation. While the obstacles to ecomarkets are daunting, the status quo is resulting in the rapid destruction of valuable coastal ecosystems, livelihoods, and communities. Carefully designed and implemented ecomarkets have the potential to enable communities to diversify resource use, and focus on long-term stewardship and conservation while meeting pressing development, food security, and human welfare goals.

22D Economic valuation & market-based conservation
Thursday 12 July, 1115, Hall C

Decision making tools: how to best manage the coral reefs?

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When the biologist Garret Hardin put forth his 'tragedy of the commons' in 1968, he assumed that multiple individuals, acting independently and rationally consulting their own self-interest, will ultimately deplete a shared limited resource. Nobel Prize-winning economist Elinor Ostrom believes that if users decide to cooperate with one another, monitoring each other's use of the resource and enforcing rules for managing it, they can avoid the tragedy. For Ostrom, social control mechanisms and collective actions regulate the use of the commons. In her 1990 book 'Governing the Commons', she demonstrated that informal approaches to managing common property resources are superior to government-enforced ones. Hardin revised his theory and called it 'The Tragedy of the Unmanaged Commons'. Cooperative behaviour is the key to success when commons are used as a framework for solving environmental problems. In fact, private sector institutions cannot solve alone nationwide problems such as global warming. The decision has to be taken at different levels. That is why we think that game theory is an appropriate mathematical tool for structuring and analysing problems of strategic choices in an interactive environment. It models a very wide range of situations between interacting decision-makers who are supposed to enumerate the players, their strategic options, preferences and reactions. Nash theorem took its root in Leon Walras' General Equilibrium Theory (1874) and John von Neumann's and Oskar Morgentern's Game theory (1944). Is it possible and appropriate to reach a Nash equilibrium when the goal is to protect coral reef?

22D Economic valuation & market-based conservation
Thursday 12 July, 1715, Hall C

Identification of novel antiviral activities from coral reef organisms

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Coral reefs represent an invaluable source of new bioactive molecules for biomedical research and the pharmaceutical industry. While numerous promising candidate molecules have been isolated from coral reef organisms, mainly from sponges and tunicates, large areas still remain unexplored. This opens up opportunities for future coral reef-based innovations which could in turn contribute to the preservation of these precious ecosystems via a financial incentive. Major drawbacks of marine natural products drug discovery include the availability of appropriate assay technologies for rapid high-throughput testing of crude biological extracts, as well as the supply of sufficient amounts of purified active compounds needed for clinical testing. Therefore, our group develops novel technologies for the discovery and production of bioactive molecules from coral reefs. Here we present the large-scale application of a new cell-based technology for the combined discovery and analysis of HIV-inhibitory activities (EASY-HIT) on extracts of coral reef organisms. We have combined EASY-HIT with high-content analysis approaches, as well as single-target assay technologies, to comprehensively characterize bioactive materials from coral reefs. Several extracts showed potent HIV inhibitory activities against various targets of the viral replication cycle and effects on related cellular features.

22D Economic valuation & market-based conservation
Thursday 12 July, 1700, Hall C

Resilience through mutual co-operation between local and international communities

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We apply an approach that allows groups that are spatially distant and differ culturally and economically to co-invest in resilience. Local communities and international philanthropic entities magnify their measurable impact when they co-operate. The approach is applied in the Pacific Region to assist communities in acquiring resources dedicated to continuous management interventions for 20 years or more. A bundled intervention package includes no-take areas, catch limits, and base monitoring. Current annual costs are about $US5/hectare. We are applying lessons from three existing sites in Micronesia to expand the reach and efficacy of the approach as we attempt to develop a network of 20+ sites. The approach employs an iterative process through which each party periodically receives a signal from the other and responds. As philanthropists receive a signal that verifies local performance, they are stimulated to maintain or increase investments. Continued investment stimulates local entities to respond with continued performance. Non-compliance is discouraged through third-party monitoring, rules, and sanctions. A primary goal is to build a self-reinforcing mechanism that creates a 'stable state' relationship between the two parties. Finally, we report on efforts to extend the relationship beyond the two primary parties to include governments, bi-lateral organizations, and others, who can also co-invest.

22D Economic valuation & market-based conservation
Thursday 12 July, 1545, Hall C

The worth of coastal ecosystems: a review of economic valuation studies in the Coral Triangle

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In the last decade, much progress has been made in articulating coastal environmental services, and the way they contribute to a range of economic production and consumption activities. Economics contributes to understanding the flow of ecosystem services through the estimation of the economic values of those services. In the Coral Triangle region, economic valuation studies of the environment began to flourish in the 1980s, particularly in Indonesia and the Philippines, and since then, have been widely implemented. This study reviews more than one hundred economic valuation studies related to the region's coastal and marine ecosystems and their services. In addition to amassing data for a valuation database, the study also describes the attributes of those studies, amongst others, the type of ecosystem services being valued, the estimation technique used, the distribution of economic benefits according to type of economic agent, their location (whether local, regional or global) and timeframe (short versus medium or long term), and the resulting estimated values. Based on these attributes, we provide recommendations to address valuation gaps, and ways of using these valuation studies to advocate for sustainable management of coastal and marine resources.

22D Economic valuation & market-based conservation
Thursday 12 July, 1515, Hall C

Capturing Malagasy fisher communities' non-market economic values using mixed methods

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Understanding how people value ecosystem goods and services can provide important information to managers and planners. Valuations of marine protected areas often focus on marketed goods and services. For many traditional fisherfolk, however, non-marketed ecosystem services are critically important inputs to their wellbeing. Using discrete choice experiments (DCEs), we quantify the values that Vezo fisherfolk of southwestern Madagascar place on three non-marketed services: (1) the likelihood that their offspring will be able to follow their parents' livelihoods as traditional fishers (bequest value); (2) increased social cooperation between villages (social capital); and (3) storm protection. The DCE was conducted in 2010 as part of a comprehensive Total Economic Valuation (TEV) of ecosystem services flowing from a community-managed marine area in southwest Madagascar. The TEV included provisioning (fisheries, wood, shells, freshwater, medicinal plants, research, and tourism), regulating (organic waste disposal, carbon sequestration, and storm protection), and cultural (social capital represented by levels of inter-village cooperation and respect, and intra-village conflict about marine resource use; cultural heritage represented as a bequest value; education; recreation; and spiritual) ecosystem services. We present values for all ecosystem services measured in the valuation, along with interpretations of differences between groups and methods. We triangulate a number of the values using multiple methods, including market-based, ranking and rating, and Likert-scale rating. Despite their reputation as 'living for each day', we find that bequest values constitute an important value that local Vezo fisherfolk place on the marine and coastal environment.

22D Economic valuation & market-based conservation
Thursday 12 July, 1200, Hall C

What impacts to expect from economic valuation of coral reefs?

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We analyzed five economic studies conducted on the management of coral reefs in the Pacific. These studies were conducted in response to specific requests from a diverse list of stakeholders from a range of countries (Fiji, French Polynesia, Kiribati, New Caledonia and Vanuatu); and they used a variety of economic approaches that range from total economic valuation of ecosystem services to ex-post cost-benefit analysis of MPAs through economic assessments of impacts. The expected outcomes for these studies were to 'inform & convince' the different types of stakeholders and to support decision making processes by providing economic comparisons of policy choices. We present the main challenges faced in conducting these studies in the context of the South Pacific, and we highlight the importance of non-commercial fisheries, local culture and the place of the subsistence and community economy. We found that the effect on policy decisions was varied and, in general, lower than expected, although in some cases the time span may have been too short to accurately evaluate the effectiveness of these studies. We recommend actions to improve this situation, which include better matching of economic studies to policy questions, improved valuation methods and improved methods to inform decision-makers about alternative policy scenarios. Priority must be given to strategies that directly deal with positive and negative externalities, such as Payments for Ecosystem Services, taxes or compensations. For these strategies, specific valuations are used to 'fine-tune' the economic tool.

22D Economic valuation & market-based conservation
Thursday 12 July, 1145, Hall C

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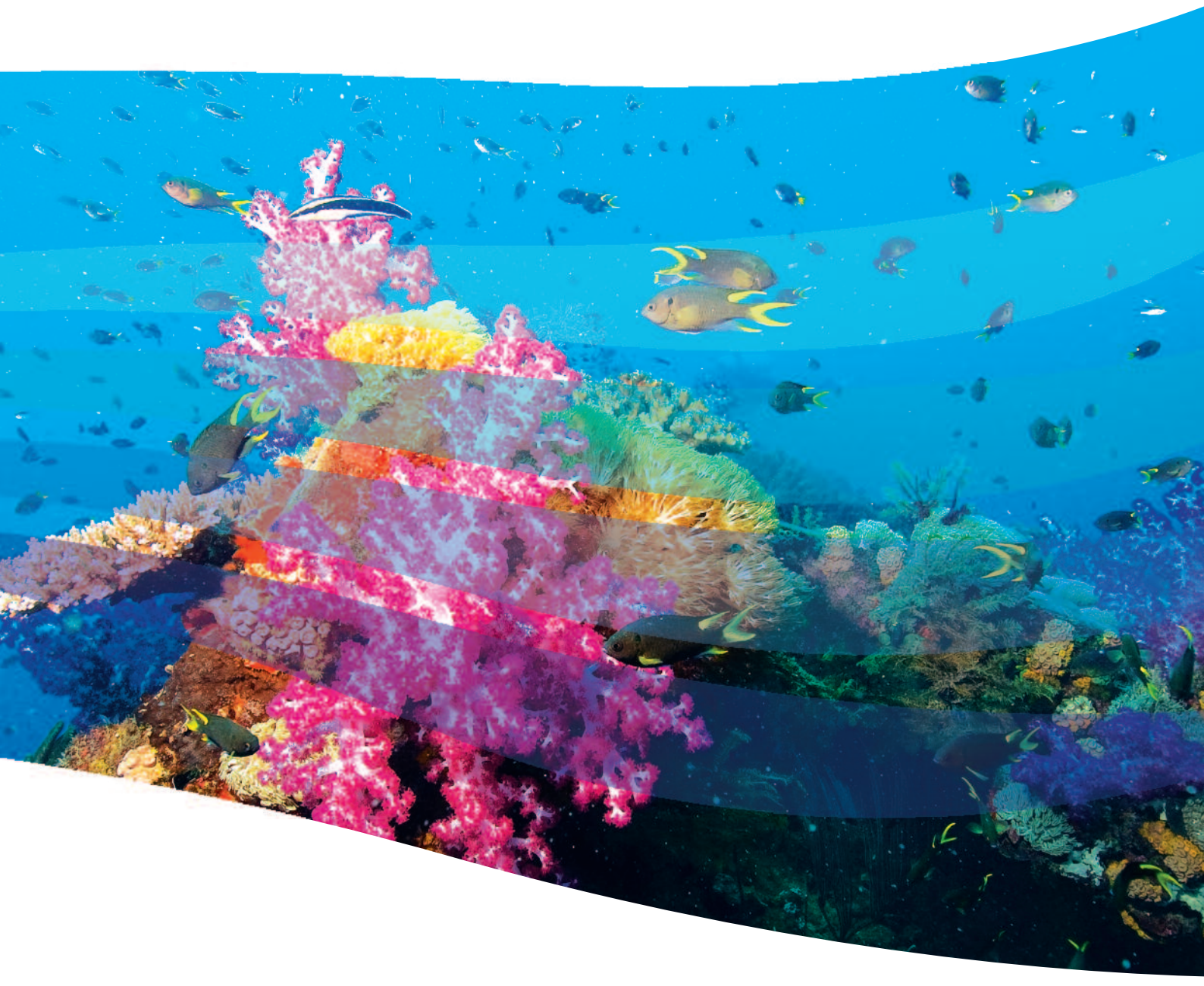

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