Appendix F19

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The Status of Shallow-water Coral and Fish Communities at Scott Reef Annual Report, 2008

BROWSE FLNG DEVELOPMENT
Draft Environmental Impact Statement

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The Status of Shallow-Water Coral and Fish Communities at Scott Reef: 2008

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Preamble

Scope of Works

The Australian Institute of Marine Science (AIMS) entered into a contract (No. 4600001754) with Woodside Energy Limited (WEL), as agent for the Browse Joint Venture Partners (JVP), on 28 February 2008, to undertake a three year research program at Scott Reef. For the purpose of this report, this research program is known as the Scott Reef Research Project (SRRP).

The research within the SRRP is divided among three projects, and each project is required to submit an annual report to WEL and the Browse JVP as part of their contractual requirements. This annual report for 2008 summarises the research of Project 1: Understanding the shallow-water coral and fish communities. The report specifically summarises the data collected in the first two field trips, in March and April/May 2008, but also discusses these data in the context of AIMS' monitoring of coral and fish communities at Scott Reef since 1994. The report follows a standard scientific format agreed with WEL. Additionally, the report includes specific responses to questions provided by WEL; these questions in the format supplied are as follows.

Project 1

Sub-project 1.1

- *What is the status of the biological communities at Scott Reef?*
- *Has the biological communities changed in the last 12 months? If so, what were the drivers?*
- *Has any major mortality events or processes been seen at Scott Reef (e.g. Disease, COTS, physical damage)?*
- *What has been the temperature regime at Scott Reef in the last 12 months?*
- *Was there any NOAA bleaching alerts?*
- *Was there any major temperature anomalies?*
- *Any bleaching of corals associated with these events?*
- *What was the sediment deposition at the monitoring sites at Scott Reef? How did it vary between locations? How does it compare with other reef locations?*

Sub-project 1.2

Tagged corals

- *What was the survival and growth rates of corals at Scott Reef in the last 12 months?*
- *How does these rates compare to corals at other reefs? If there are major differences, can AIMS suggest why?*
- *What were the mortality drivers of the tagged corals (if known)?*

Sub-project 1.3

- *Please provide a summary of the methodology, i.e. in three paragraphs.*
- *Based on published data could input of larvae from Scott Reef maintain fish populations at Rowley Shoals?*

Sub-project 1.4

Coral Spawning

- *What species spawned in March 2008?*
- *What percentage of species spawned (of those sampled)?*
- *What percentage of individual species spawned?*
- *How does this compare to the October 2007?*

Coral Recruitment

- *What were the rates of recruitment at Scott Reef in 2008?*
- *How does this compare to previous years?*
- *Do these rates indicate that the reef is continuing to recover well?*
- *How does this compare with other coral reefs?*

Specific Response to WEL Questions

1.1 Long Term Monitoring

- ***What is the status of the biological communities at Scott Reef?***

Benthic communities

The cover of hard corals at Scott Reef is now similar to that prior (1997) to the bleaching, although the cover of soft corals remains at approximately half that prior to the bleaching. On average, the total cover (± S.E.) of hard corals in 2008 was 37% (± 1), compared to 42% (± 2) in 1997, whereas the cover of soft corals was 4% (± 1), well below that (8% ± 1) in 1997.

The recovery of hard corals and the changes in cover ten years after the bleaching varied among the permanent monitoring locations at Scott Reef. The initial (1998-2004) increases in coral cover were most rapid at locations (SL1, SL2, SL3, SL4) least affected by the bleaching, and slowest at the worst affected locations (SS1, SS2). However, there was a different pattern of recovery in more recent years (2004-2008); the locations with the fastest (SL1, SL2, SS1, SS2) or slowest (SL3, SL4) increases in cover differed from those shortly after the bleaching. Different patterns of change among the locations ten years after the bleaching reflect the impact of cyclones. In 2004, Category 5 Cyclone Fay passed directly over Scott Reef, and there were subsequent decreases in mean coral cover at locations SL2, SS1 and SS2. Three years later (2007), Cyclone George passed to the south of Scott Reef; the smaller relative increases in coral cover at locations SL3 and SL4 between 2004 and 2008 were probably due to the impacts of Cyclone George, which was supported by the patterns of growth and survival of tagged colonies.

The dominant families of hard coral displayed different patterns of impact and recovery from the mass-bleaching in 1998, but ten years later their relative abundances were approaching those prior to the disturbance. By 2008, the mean cover of the Acroporidae and Pocilloporidae had increased to 18% (± 2) and 4% (± 1) respectively, whereas the Poritidae had increased in mean cover to 9% (± 2); the cover of Acroporidae had returned to 65% of that prior to the bleaching, whereas the cover of the Poritidae and Pocilloporidae was similar or greater than (>90%) that prior to the bleaching.

The cover of all benthic groups (hard corals, soft corals, sponges) decreased by at least a half following the mass-bleaching in 1998, with the exception of the turfing and coralline algae that increased in cover. Changes in the relative abundances of the Acroporidae, Poritidae and Faviidae drove the structural changes in the hard coral communities at different sites, from communities previously dominated by branching *Acropora* (47%) and other branching corals (9%), to communities with a lower coral cover in which massive corals had the highest (45%) relative abundance. During 2004 there were few changes in the benthic community at Scott Reef. Turfing and coralline algae remained the dominant benthic group at all locations, and the cover of soft corals and sponges remained low. However, decreases in the cover of algae since the bleaching were matched by increases in coral cover, which were similar for the branching *Acropora*, other branching corals, tabulate, foliaceous, and massive corals. Consequently, the branching *Acropora* had returned to only 21% of its previous cover, whereas the massive corals and tabulate corals had returned to 59 and 100% of their previous cover, respectively; the other groups had returned to between 30 and 40% of their previous cover. By 2008, ten years after the bleaching, communities continued the return to their previous structure, but the cover of turfing and coralline algae was still higher than that prior to the bleaching and there was an increased cover of tabulate corals and sponges. Following small increases between 2004 and 2008, the cover of soft corals was approximately half that prior to the bleaching. Similarly, there were small increases and decreases in the cover of branching *Acropora* and other branching corals at sites across Scott Reef, and the groups had returned to between 25% and 47% of their cover prior to the bleaching, respectively. The massive corals (e.g. Poritidae, Faviidae) continued to increase in cover at some sites, but with small decreases at other sites; their cover in 2008 reached approximately 60% of that prior to the bleaching. Of all benthic groups, the most notable changes between 2004 and 2008 were the increases in cover of tabulate corals and sponges. Tabulate corals were largely composed of species of *Acropora* with table or corymbose growth forms, and had increased at most sites to a mean cover of 5%, compared to <1% prior to the bleaching. Sponges also had large relative increases in cover at most sites, to a mean cover of 3%, compared to <1% prior to the bleaching. Across Scott Reef, the mean shift in community structure following the bleaching, and the return towards a similar structure to that prior to the bleaching, was clearly illustrated in multivariate analyses. In particular, there was an obvious shift in community structure following the bleaching (1998), and the early post-bleaching years (1998 – 2000) grouped together; then, a noticeable shift away from the post-bleaching state and a grouping of the years 2001 to 2004; then, a small shift away from the pre-bleaching structure following cyclone disturbance in 2004; after 2004 there was a noticeable shift towards the pre-bleaching structure of communities, with the cover of some high order benthic categories (e.g. hard corals, algae) being similar to that prior to the bleaching. Although the cover of high level benthic categories at Scott Reef in 2008 was similar to that prior to the bleaching, there was some variation among locations and among more detailed benthic categories (e.g. branching *Acropora*, tabulate corals). Thus, directional shifts in community composition between 2001 and 2008 were towards the pre-bleaching state, but not to the same community structure, or location in multivariate space.

As with the changes in the total cover of hard corals, the changes in the cover of corals with different growth forms reflected the exposure of sites to the regimes of disturbance. For example, the small changes in the abundance of branching corals and the large increases in the abundance of tabulate corals in recent years (>2004) may reflect a combination of successional recovery following the bleaching and the local impacts of cyclone disturbance. At most of the sites least affected by the bleaching, the cover of branching corals had decreased in recent years, rather than the further increases that were expected. However, these sites (e.g. at locations SL3, SL4) were also among those most exposed to recent (2006) cyclone disturbances that impact branching corals; the increases in the cover of massive corals over the same period were also largest at these sites. In contrast, the largest increases in the cover of the tabulate corals and sponges were at the sites worst affected by the bleaching, where the decreases in the cover of branching corals were most significant. Thus, the increases in the cover of tabulate corals may reflect the successional changes in the community structure following a major disturbance. In the absence of further disturbances, the abundances of branching corals would be expected to increase further, due to their high rates of growth, local recruitment, and ability to outcompete (overtop) other benthic organisms. The extent to which branching corals again dominate at many sites across Scott Reef, and the benthic communities return to their previous cover and structure, depends on the regime of disturbance in the future. In particular, the frequency and severity of cyclone disturbances and whether communities are again exposed to extreme water temperatures arising from climate change.

Fish Communities

Differences in the fish communities at locations across Scott Reef reflect the differences in habitat and exposure to hydrodynamic factors such as oceanic waves, tidal intrusions and wind fetch. For example, there is a clear separation in community structure among locations according to oceanographic conditions; SL2 separates out most significantly, then SL1 and SL3, then SL4 and SS1, and then SS2. Not withstanding the importance of location, major differences in species composition and abundance were associated with the varying rates of coral recovery following the 1998 bleaching event and the passing of the category five Cyclone Fay in 2004. The 1998 coral bleaching event is the major overlying influence observed during 15 years of monitoring.

Five or more years after the 1998 bleaching event, the fish assemblages at Scott Reef were very different to those prior to the disturbance, irrespective of location. The structure of the fish communities was maintained after the bleaching and signs of recovery typically lagged by 12 - 18 months, with the greatest changes occurring after this period. More recently (>2004), all communities have shifted in structure since the bleaching, with the direction of that shift demonstrating that the composition of the fish communities are still quite different to those prior to the bleaching. This contrasts with the trajectory of change demonstrated by the benthic assemblage which is more towards a pre-bleaching state. In general, many of the larger more mobile fish species have continued to increase in abundance over the monitoring period and now are more abundant than prior to the bleaching; smaller more site attached fish species displayed a more complicated pattern of change that can vary according to their habitat preferences. Abundances of fish species heavily dependent on hard coral for food and/or shelter were low during the post-bleaching phase (1998-2004) but now shown signs of increasing with the cover of hard corals (2005-2008). In contrast, the increasing abundance of species with a dietary preference for algae after the bleaching (1998-2004) has since (>2004) become a decline, following the corresponding decrease in algae. Similarly, the increased abundance of tabulate corals at some sites across Scott Reef may result in an increased abundance of fish species in the future that utilise these corals for habitat.

- ***Has the biological communities changed in the last 12 months? If so, what were the drivers?***

There have been no major disturbances or changes in the biological communities at Scott Reef in the last 12 months. In the last year, the coral and fish communities have continued to recover from the mass-bleaching in 1998 and more recent and localised impacts of Cyclone Fay in March 2004 and Cyclone George in March 2007. Total abundances of the larger more mobile fish species are higher in 2008 than in any of the previously studied years. Future analyses taking into account the trophic categories of fish species may disentangle the main drivers for this increase. The fish assemblages at Scott Reef in 2008 have maintained their post-bleaching composition and an obvious shift towards a pre-bleaching state has not occurred, however, there is evidence that the assemblages are continually changing. Certain fish species that are more reliant on hard coral (e.g. *Chromis ternatensis*) have continued to increase as the cover of hard coral cover increases, whereas numbers of herbivorous species, e.g. *Plectroglyphidodon lacrymatus*, have continued to decrease through 2008 as the contribution of algal cover has similarly decreased.

- ***Have any major mortality events or processes been seen at Scott Reef (eg. Disease, COTS, physical damage)?***

Major mortality events at Scott Reef in the last decade are currently limited to the impacts of bleaching from elevated water temperatures in 1998, and some physical damage from Cyclone Fay in March 2004 and Cyclone George in March 2007. There have been no major mortality events in the last year.

- ***What has been the temperature regime at Scott Reef in the last 12 months?***

Water temperatures in shallow (*ca* 9 m) waters at Scott Reef followed a seasonal cycle of a high in May 2007 (*ca* 30.0˚C), a winter low in August 2007 (*ca* 26.5˚C), and an increase through two bimodal summer peaks of *ca* 30.5˚C in December 2007 and February 2008. The bi-modal peaks in water temperature and the decrease during January is likely due to monsoonal cloud cover and increased wind speeds.

Water temperature did not exceed and sustain the estimated bleaching threshold of approximately 31˚C. There was minimal variation in mean daily water temperature between locations SL1 and SS2, however temperatures were consistently 0.5˚C lower at SL3. The cooler temperatures at SL3 are a consequence of the tidal incursions cooler oceanic water between West Hook and Sandy Islet. The cooling tidal influence, which is strongest during spring tides, increases with proximity to the deep channels between West Hook and the Sandy Islet, and between North and South Scott Reef.

- ***Were there any NOAA bleaching alerts?***

The NOAA forecast system uses modelled sea surface temperature (SST) forecasts to develop maps of potential coral bleaching severity during the bleaching season (January-March for the southern hemisphere). On 12 August 2008, the NOAA Coral Reef Watch Service forecast the potential for bleaching in the Scott Reef region between August and November 2008. Additionally, the potential for widespread bleaching has since been forecast for the waters to the north-east of Scott Reef between September and December 2008.

- ***Were there any major temperature anomalies?***

Temperature loggers are deployed at each of the long-term monitoring locations (9m depth) at Scott Reef and retrieved on each trip, three times a year. Data downloaded in February/March, and April/May 2008 indicated no major temperature anomalies at Scott Reef in the last year.

- ***Any bleaching of corals associated with these events?***

In two trips to Scott Reef in February/March, and April/May 2008, there was no evidence of coral bleaching at Scott Reef in the last year.

- ***What was the sediment deposition at the monitoring sites at Scott Reef? How did it vary between locations? How does it compare with other reef locations?***

Mean sedimentation rates in shallow water at Scott Reef between February and April 2008 ranged from a low of 0.45 mg cm^{-2} d^{-1} at SL2 to a high of 1.25 mg cm^{-2} d^{-1} at SL1. These rates are at the lower extent of the range (< 1 to 10 mg cm ^{2} d^{-1}) expected at reefs not subjected to stresses from human activities (e.g. (Rogers 1990). These rates are consistent with mean deposition rates at clear water sites in north-western Australia and New Guinea where mean deposition rates were 1.4 mg cm ^{2} d^{-1} and 1.0 mg cm ^{2} d^{-1}, respectively, and are comparable to those recorded at reef locations in Jamaica and the U.S. Virgin Islands where values ranged from 0.1-1.6 mg cm ^{2} d^{-1} (Dodge et al. 1974; Simpson 1988).

1.2 Coral Demography

- ***What was the survival and growth rates of corals at Scott Reef in the last 12 months; what were the mortality drivers of the tagged corals (if known)?***

The mean rates of survival and growth of *Acropora spicifera* colonies at Scott Reef in the last year (June 2007 to June 2008) were similar to the previous year, and varied according to their exposure to cyclone disturbance and susceptibility of their different size classes. Differences in growth and survival among locations and size classes were consistent over the two year study period, reflecting the impact of Cyclone George in March 2007. Because Cyclone George occurred at the end of one survey period (June 2006 to June 2007), and shortly before the next (June 2007 to May 2008), its impacts were evident over two survey intervals.

Colonies at locations SL3 and SL4 were worst impacted by Cyclone George, having low rates of growth and survival, particularly the largest size classes. The survival of colonies at SL3 ranged from 10 to 90% yr^{-1}, between 2006 and 2008, and growth ranged from a mean decrease in diameter of -4 cm to a mean increase of 6 cm yr^{-1}, depending on size class. Similarly, the survival of colonies at SL4 ranged from 15 to 90% yr^{-1} between 2006 and 2008, and the growth rates of colonies ranged from a mean decrease in diameter of -14 cm to a mean increase of 4 cm yr^{-1}, depending on size class. At both SL3 and SL4, the larger colonies were most susceptible to the wave energy generated by the cyclone, and had the lowest rates of survival and a high incidence of negative growth following injury and the loss of live tissue. At both locations the rates of survival for colonies > 25 cm diameter were <30% yr^{-1} between the 2006 and 2007, and 2007 and 2008 surveys. The low rates of survival for the largest (> 25 cm) colonies between June 2007 and June 2008, several months after the cyclone (March 2007), were due to the eventual mortality of injured colonies.

Location SL1, and particularly SL2, were more sheltered from the impact of Cyclone George than SL3 and SL4, and had higher rates of growth and survival that were similar across the size classes. The survival of colonies of all sizes classes over the two year period ranged between 75 and 90% yr^{-1} at SL1, and was > 94% yr^{-1} at SL2; rates of growth ranged between 2.5 and 5.5 cm yr^{-1} at SL1, and between 4.5 and 10.1 cm yr^{-1} at SL2.

- ***How do these rates compare to corals at other reefs: If there are major differences, can AIMS suggest why?***

Preliminary data and literature searches indicate that the rates of growth and survival of *Acropora spicifera* at Scott Reef in the absence of cyclones are particularly high, and similar across size classes. In contrast, the survival of corals at reefs exposed to more localised anthropogenic disturbances (e.g. overfishing, degraded water quality) is generally lower and more size-specific, with smaller corals having lower rates of survival than larger corals. This size-specific survival may be due to the disproportionate impact of algal competition and sedimentation on the smallest corals; whereas Scott Reef has a low abundance of macroalgae and low rates of sedimentation. Thus, in contrast to other published results, the mean rates of survival for small colonies at Scott Reef over several years may prove to be higher than for larger colonies, which are more susceptible to cyclone disturbance. Data collection over several years is required to confirm these initial patterns of growth and survival, and their responses to different disturbance regimes and the increasing density of corals as communities continue to recover from the bleaching.

1.3 Genetic Connectivity of Coral and Fish

- ***Please provide a summary of the methodology, i.e. in three paragraphs***

Genetic studies have important practical and theoretical advantages over other methods for inferring patterns of connectivity. These methods utilise the inherent differences in the DNA sequences of individual genomes that accumulate through selection or drift when gene flow is restricted. Well-developed theoretical models utilise either gene frequencies (e.g. allozyme and microsatellite data), or genealogical relationships of specific DNA sequences (e.g. mitochondrial DNA sequences), to measure the spatial distribution of genetic variation, allowing assessment of the genetic similarity of populations and subpopulations. This allows for estimation of the extent of genetic mixing, and thus provides an effective method to investigate the influence of dispersal and subsequent recruitment on the distribution of molecular variants.

There are many different molecular tools that can be applied for maximum benefit to different biological questions. Microsatellite markers, have several attributes that make them the marker of choice for addressing ecological questions. Between 30 and 60 specimens from at least six sites from each of Scott Reef and Rowley Shoals will be genotyped with microsatellites. These sample sizes will provide strong statistical power for detecting population differentiation within and among reefs and systems using an Analysis of Molecular Variance, as well as for applying a model-based clustering method to infer the most likely number of populations in the data set. If the level of population division is sufficiently large, recent migrants will also be identified using assignment tests. In addition to microsatellites, mitochondrial DNA (mtDNA) markers will also be utilised in the fish study to compliment the microsatellite data. The mtDNA is useful for delineating evolutionary significant units and management units, as well as reconstructing past demographic processes (for example bottlenecks, population size expansions).

Two fish species that differ in life histories and behaviour are being used as representative models in this study. *Chromis margeritifer* is a common pomacentrid that lives in close association with live branching corals and is more abundant in exposed slope habitats. This species lays demersal eggs and once hatched, larvae live in the pelagic environment for between 30 and 36 days. This mode of reproduction is common in these reefs, and the pelagic larval duration is relatively high for fish that associate with live coral. Therefore, *C. margeritifer* will provide a good representation of many coral reef fish that have a relatively high potential for long-distance dispersal. *Cheilodipterus artus* is a common apogonid cardinal fish which broods its eggs in its mouth before releasing larvae that spend about three weeks in the plankton before they settle. These apogonids live in much more sheltered water in lagoons, congregate in schools under reef overhangs, and are patchier in their distribution compared with *C. margeritifer*. In addition, adult cardinal fish have strong homing behaviour to their diurnal resting sites. Therefore, the genetic structure of *C. artus* is likely to be representative of those coral reef fish with limited dispersal potential. The expectation is that the apogonid will exhibit increased genetic structure compared to the pomacentrid.

- ***Based on published data could input of larvae from Scott Reef maintain fish populations at Rowley Shoals and vice versa?***

Genetic data from a brooding and a broadcast spawning coral at Scott Reef and the Rowley Shoals showed that the majority of larvae of both species were retained on their natal reef or reef patch (Underwood et al. 2007; Underwood et al. in press). The conclusion is that short-term recovery of these coral communities after severe disturbance requires the input of larvae from viable communities, kilometres to a few tens of kilometres away. Therefore, the isolated reef systems of northwest Australia clearly rely on their own production of larvae for the ecological maintenance of populations. It seems that oceanographic mechanisms of retention, a propensity for coral larvae to settle within a week, and reduction in numbers of larvae though predation and dilution in the open ocean, mean that successful long-distance dispersal of coral larvae over hundreds of kilometres is rare.

In contrast to coral larvae, the larvae of coral reef fish typically have longer obligate pelagic larval durations (PLD), as well as an ability to influence their own dispersal trajectories through more advanced swimming, sensing and feeding capabilities. These biological characteristics will affect the routine and rare dispersal distances of larvae, but so far, no published research has explored patterns of connectivity of fish among the offshore reefs of northwest Australia. Estimates of water particle transport from satellite tracked drifters and mean current speeds, show that dispersal of particles between Scott Reef and Rowley Shoals takes about a month (Gilmour et al. in press). Therefore, for species with relatively short PLD's, it is unlikely that larvae exchanged between Scott Reef and Rowley Shoals make significant contributions to recruitment and maintenance of populations at these systems. With respect to species with longer PLD's, the pattern of connectivity is more complex and less predictable. Considerable evidence from the literature indicates that larvae of many fish species, including those with relatively long PLD's, self-recruit back to their source populations (Swearer et al. 1999; Cowen et al. 2000; Swearer et al. 2002). The primary biological mechanism of retention seems to be the ability of larvae to migrate vertically, actively swim against currents and to sense and swim towards home reefs, thereby increasing rates of self-recruitment. In addition, there are physical mechanisms that retain larvae in the vicinity of natal reefs including; island wake effects, tidally driven vertical mixing of water, topographic complexity of coastlines, and coastal boundary layers of reduced flow-speeds near the shore, which all increase residence times of water particles (and potentially larvae) near reefs (Largier 2003). However, the ability of fish larvae to feed on the plankton, to sense and swim to reefs from many kilometres away, and a putative ability to delay metamorphosis, increases the chances that larvae may successfully disperse between Scott Reef and Rowley Shoals. Such long-distance transport between systems is likely to be important for gene exchange and hence patterns of genetic diversification over intermediate to long-term time scales (more than hundreds of years), but the strength and regularity of such connections relevant to the maintenance of populations over ecological time scales (years to tens of years)of is currently unknown.

1.4 Coral Reproduction and Recruitment

- ***What species spawned in March 2008: what percentage of species and colonies spawned?***

The developmental stage of coral eggs during March 2008 provides further support that autumn is the dominant coral spawning period at Scott Reef. In total, 220 colonies from 48 species of scleractinian corals (16 genera, eight families) were scored at 5 locations across Scott Reef, of which 86% of all colonies, and at least 83% of all species, were expected to spawn in autumn, based on the presence of pigmented eggs within colonies. In the *Acropora* genus, a total of 195 colonies from 32 species were sampled, of which 84% of colonies and 81% of species were expected to spawn in autumn.

Of the species and colonies predicted to spawn in autumn, the proportion spawning following the full moon in March versus April was uncertain. It was assumed that colonies with large and pigmented eggs spawned during March, whereas those with unpigmented eggs spawned in April. However, a rapid visual survey conducted in early April 2008 suggested that many of the colonies expected to spawn after the full moon in April, had already spawned after the full moon in March, in contrast to what was expected based on egg pigmentation. Approximately 100 colonies of locally dominant *Acropora* species were visually surveyed for eggs at locations SL3, SL4, and SS1. With the exception of the brooding corals *A. brueggemanni, A. palifera*, and *Seriatopora hystrix,* none of the corals that were examined in April had visible eggs. Thus, many of the 86% of colonies (n = 220) and 83% of species (n = 48) known to spawn in autumn, may have done so in the month of March. This pattern of egg development and spawning was unusual, because it indicates that at least some colonies spawned unpigmented eggs, or that eggs became pigmented closer (< 3 weeks) to the time of spawning than expected, in contrast to most findings.

Estimates of the percentage of colonies and species participating in any spawning event are biased by non-random sampling design. Alternately, a random sampling design provides sufficient replication to elucidate patterns of reproduction in only the most common species. Thus, we will combine a stratified sampling design of reproduction with measures of relative abundances to determine the percentage of colonies and species participating in a spawning event. Data on relative abundances are yet to be analysed. This approach will be refined in an attempt to provide some quantitative measure of the relative ‘importance’ of spawning events during autumn (March – April) and spring (September – November).

- ***How does this (spawning) compare to the October 2007?***

Based on these data and those collected in October 2007, all species of *Acropora* participated in the autumn spawning, and no species spawn exclusively in spring, with the possible exception of *A. millepora*. However, there is evidence that populations of at least five species of *Acropora* participate in both autumn and spring spawning events, but it is not known whether individual colonies participate in one or both of these events. Of the 25 colonies from 16 species of non-*Acropora* scleractinian corals sampled (families Faviidae, Merulinidae, Oculinidae, and Pectiniidae), all but one colony were expected to spawn in autumn. Seasonal differences are evident between the two major spawning periods at Scott Reef, however further sampling is required to determine the role of taxonomic, spatial, and temporal variability in gametogenesis, gamete maturation, and gamete release.

- ***What were the rates of recruitment at Scott Reef in 2008: how does this compare to previous years?***

The rates of larval supply and recruitment at Scott Reef have continued to increase since the 1998 bleaching event, with a particularly large increase in 2008. The mean rates (± S.E.) of recruitment at Scott Reef have increased from < 0.3 (± 0.2) recruits plate^{-1} yr^{-1} one year after the bleaching (1999), to 2.3 (± 1.5) in 2003, and 70.4 (± 57) in 2008. On average, the rates of recruitment ten years after the bleaching in 2008 had exceeded the mean (± S.E.) pre-bleaching rate of 53 recruit’s plate^{-1} yr^{-1} in 1997. The rapid increases in recruitment in recent years (>2004) probably reflect the maturation and rapid increases in colony size from approximately 5 years after the bleaching. Thus, after 2003, there was a corresponding increase in the number of colonies of adult size and rapid increases in the percentage cover of hard corals. Given their greater number of polyps, the largest coral colonies are known to make a disproportionately high contribution to reproductive output, and therefore, rates of recruitment.

Although the mean rate of recruitment in 2008 had surpassed that prior to the bleaching, this was not the case at all locations and there was considerable spatial variation in recruitment across Scott Reef. By far the highest mean (± S.E.) rates of recruitment in 2008 were 354 (± 52) recruits plate^{-1} yr^{-1} at location SL1, which was more than four times that prior to the bleaching or that at any other location at Scott Reef. Additionally, location SL1 at the lagoon side of east hook consistently had the highest recruitment of all locations before and after the bleaching event. The high level of recruitment at location SL1 reflect the easterly flow of water through the channel between north and south Scott Reef, and the eddy on the lagoonal side of east hook that entraps larvae generated from more westerly locations. By comparison, there were much smaller increases in recruitment at all other locations after 2003, and by 2008 the mean rates of recruitment (± S.E.) at locations SL2, SL3, SL4 and SS1 ranged between 5 and 35 (± <5) recruits plate^{-1} yr^{-1} . The rates of recruitment in 2008 were similar or greater than those prior to the bleaching at all locations, with the exception of location SS2; at SS2 the mean (± S.E.) rate of recruitment in 2008 was 1.6 (± 0.4) recruits plate^{-1} yr^{-1}, which was less than 20% of that prior to the bleaching.

- ***Do these rates indicate that the reef is continuing to recover well?***

Recruitment rates in 2008 indicate the communities at most locations across Scott Reef are continuing to recover from the bleaching in 1998, and that more rapid increases in percentage cover may occur in the future. Given that recruitment rates have returned to a similar level to those prior to the bleaching at all locations (except SS2), then cover would also be expected to return to pre-bleaching levels within years.

Executive Summary

This report summarises the current status of the coral and fish communities at Scott Reef based on the research by AIMS in 2008 under the contract with WEL (No. 4600001754) and is set in the context of monitoring by AIMS commenced in 1994. In particular, the recovery of communities since the mass-coral bleaching in 1998 is discussed, as is the effect of periodic cyclone disturbance on their trajectories of recovery. The report also discusses the progress of research into the patterns of connectivity of coral and fish communities within Scott Reef, and communities at other reef systems in the region. Finally, some preliminary data are presented for the coral communities in the deep water lagoon at south Scott Reef, and variation in water temperatures and rates of sedimentation.

The general conclusions of this report are:

- The coral communities at Scott Reef are continuing to recover from the mass-bleaching in 1998, and the cover of hard corals at some locations is similar to that prior to the bleaching.
- The structure of benthic communities differs from that prior to the bleaching, with half the cover of soft corals, a higher abundance of tabulate corals and a lower abundance of branching corals.
- The fish communities are also recovering from the changes in habitat associated with the coral bleaching and cyclones, with the abundance of large fish at locations now similar or greater than that prior to the bleaching, but with the abundance of small fish varying among locations and through time.
- The current structure of fish communities differs from that prior to the bleaching, and some fish species that are strongly associated with groups of hard corals or algae have decreased or increased in abundance relative to these benthic groups.
- Preliminary data suggest that tabulate corals at Scott Reef have high rates of growth and survival, which are reduced during periodic cyclone disturbance that disproportionately impact the larger colonies.
- Patterns of genetic connectivity of corals among locations at Scott Reef and the other reef systems in the region suggest these systems are largely self-seeded, and rely on the production of larvae from within to maintain communities and facilitate recovery from disturbance.
- Patterns of genetic connectivity for fish species, that have a longer larval stage than corals and potentially a greater degree of connectivity among reef systems, are currently being analysed.
- Most species and individual corals at Scott Reef participate in a mass-spawning in autumn (March/April) each year, with a comparatively small number of species and individuals participating in a second mass-spawning in spring (October/November), but there is evidence of populations of several species participating in both spawning events.
- Rates of larval supply and recruitment of corals are now similar to those prior to the bleaching, at all but one location, reflecting the maturation of colonies that had recruited following the bleaching and suggesting more rapid increases in coral cover in future years in the absence of disturbances.
- There have been no anomalies in water temperature at Scott Reef over the past year, and rates of sedimentation were very low.

- Preliminary data indicate that the deep-water coral communities at the south Scott Reef lagoon are very different to the shallow water communities and may have regional significance, particularly given the lack of similar habitat in the region. A total of 51 scleractinian coral species from 27 genera and 11 families were recorded, including 8 new records for Scott Reef, 5 new records for Western Australia and 2 new records Australia-wide.
- The combination of data being collected in the SRRP Project 1 provides an excellent basis on which to compare the dynamics of coral and fish communities at other reefs, and determine the extent to which current ecological paradigms (e.g. from the Great Barrier Reef) apply to the Scott Reef system.

1 Introduction

1.1 Long Term Monitoring

Natural disturbances play important roles in the processes that influence the structure and dynamics of marine communities (Sousa 1984; Pickett and White 1985) and in the case of coral reef habitats, may be critical for the maintenance of species diversity (Connell 1978; Karlson and Hurd 1993; Jones and Syms 1998). Differing magnitudes of disturbances will result in varying levels of influence. For example, extreme disturbances may result in altered community composition through the elimination of species, whereas moderate levels of disturbances may promote local diversity by reducing the abundance of competitively dominant species and allowing inferior competitors to persist (Connell 1978; Petraitis et al. 1989).

Although, studies on the biological response of reef communities to natural disturbances are often experimental, several long-term datasets exist (Connell 1997). Among the most common natural disturbances to Australian coral reefs include predation by *Acanthaster planci* starfish and the winds and waves associated with cyclones. Historically, coral reef communities have been resilient to cycles of impact and recovery from these major disturbances over periods of years to decades (Connell 1997). However, since Connell's review in 1997, there is global concern that the increasing scale, frequency and diversity of disturbances to which coral reef communities are exposed will reduce their resilience and cause widespread degradation. Many of the most significant threats to coral reefs in the future have emerged only in the last ten years, many of which are a consequence of climate change, such as predicted increases in sea-water temperature, ocean acidification, outbreaks of coral disease, and an increase in severity and/or frequency of cyclone disturbances. Should this combination of disturbances cause major impacts to coral reef communities over periods of less than a decade, then the periods of recovery are unlikely to be sufficient to maintain current levels of abundance and diversity. A dramatic example of the cumulative effects of multiple disturbances is evident on coral reefs in the Caribbean, where the combination of overfishing, urchin disease and cyclones have causes a "coral–algal phase shift", whereby communities are now characterised by much lower levels of coral cover and a persistent state of high algal cover. There is now global concern that the combination of climate change, overfishing and degraded water quality are causing dramatic declines in the health and integrity or coral reef ecosystems, associated losses of biodiversity, and decreases in their social, cultural and economic values (Hughes et al. 2000; McManus et al. 2000; Pratchett et al. 2008).

Long-term studies that quantify the impact and recovery from major disturbances are invaluable to our understanding of the current and future resilience of coral reef ecosystems in a changing world. In particular, studies that discriminate the relative impact of natural and anthropogenic disturbances on coral and fish communities provide insights into the periods of recovery, and the extent to which these periods vary according to the synergisms between natural and anthropogenic disturbances. However, decreases in the numbers of coral reefs free of local anthropogenic impacts (e.g. over-fishing, degraded water quality) means there are fewer case studies with which to compare the periods of recovery following impacts from natural (e.g. cyclones) or global (e.g. elevated water temperatures) disturbances. Therefore, studies at Scott Reef quantifying the local impacts of cyclone disturbance and the wide-spread impact of mass-coral bleaching in the last decade provide valuable insights into the resilience of coral reef communities in the absence of some major anthropogenic stressors affecting coral reefs world-wide (e.g. commercial or recreational fishing, degraded water quality);

however, traditional fishing of some animals (e.g. species of sea cucumber, trochus and shark) at Scott Reef has been intense.

The Scott Reef system is ideally suited to studies of the impacts of cyclones and elevated water temperatures on coral communities because its distance from the mainland means it is not exposed to many of the anthropogenic stressors affecting other reefs around the world, such as overfishing of predatory and herbivorous fishes and degraded water quality from terrestrial runoff. However, the coral communities at Scott Reef are exposed to a high frequency (< decades) of cyclonic activity and were exposed to elevated water temperatures causing mass-coral bleaching in 1998. Since 1994, long-term monitoring of the coral and fish communities has quantified their resilience to this cycle of disturbances, in the absence of other localised stressors.

Since monitoring at Scott Reef began (1994), disturbances to the system were primarily extreme water temperatures in 1998, and periodic cyclone disturbance. Seawater temperatures at Scott Reef rarely exceed 31˚C at 16m depth, whereas for two months (March and April) in 1998 temperatures ranged between 30 and 32˚C. As a result, there was a catastrophic mortality of corals across all study sites at Scott Reef, and in a range of habitats and depths down to 20m. In contrast, cyclone disturbances at Scott Reef tend to have more localized and heterogeneous impacts, but also occur more frequently. On average, at least 1 cyclone develops in the region of Scott Reef each year. Since monitoring commenced in 1994, there were major impacts to coral communities in March 2004 from Cyclone Fay (Gilmour 2004; Gilmour and Smith 2006), and there has since been a further four cyclones that passed within the vicinity of Scott Reef (Table 1). Category 5 Cyclone Fay passed directly over Scott Reef in March 2004, at which time it had a central pressure of 905 HPa and wind speeds of over 300 km per hour. Tropical Cyclones Raymond and George passed within 50km of Scott Reef in January 2005 and March 2007, respectively (Fig. 1, Fig. 2 & Fig. 3).

Category 2 Cyclone George passed Scott Reef on 6th March 2007, with maximum wind speed of 92 km h^{-1}; Category 1 Cyclone Raymond developed close to Scott Reef but with maximum winds speeds of < 60 km h^{-1}. Cyclones Clare and Glenda passed in the vicinity (80 to 150 km) of Scott Reef in January and March of 2006, respectively. Of all these cyclones, Cyclone Fay and Cyclone George are thought to have had at least a moderate impact on the coral communities at Scott Reef, with little impact arising from the other cyclones. As each of these cyclones passed below Scott Reef the wind direction would predominantly be from the west or south as it passed near Scott Reef. Based on this information, the locations that were likely to have been affected most by the associated increase in wave motion were the relatively exposed SL3, SL4 and SS1 locations.

Table 1. Cyclones that have passed in the vicinity of Scott Reef since 2004.

Year	Month	Day	Cyclone	Central Pressure (hPa)	Maximum wind speed (km/h)	Min dist. Scott Reef (km)
2004	March	21	Fay	905	300	0
2005	January	1	Raymond	995	56	<50
2006	January	7	Clare	994	84	120
	March	27	Glenda	950	150	110
2007	March	6	George	976	92	<50

Fig. 1 Track of category 5 Cyclone Fay along long the north-Western Australian coastline, and directly over Scott Reef in 2004. Insert, meteorological picture illustrating the scale of Cyclone Fay adjacent to Western Australia.

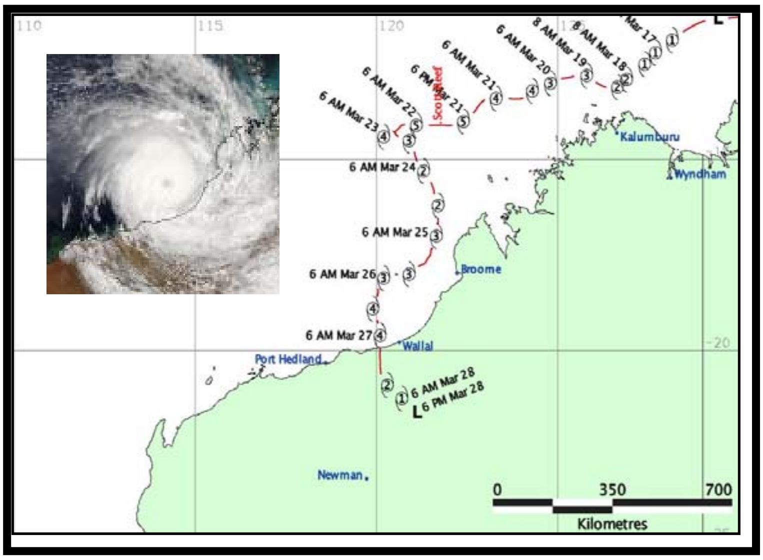


Fig. 2 Track of Tropical Cyclone Raymond in 2005.

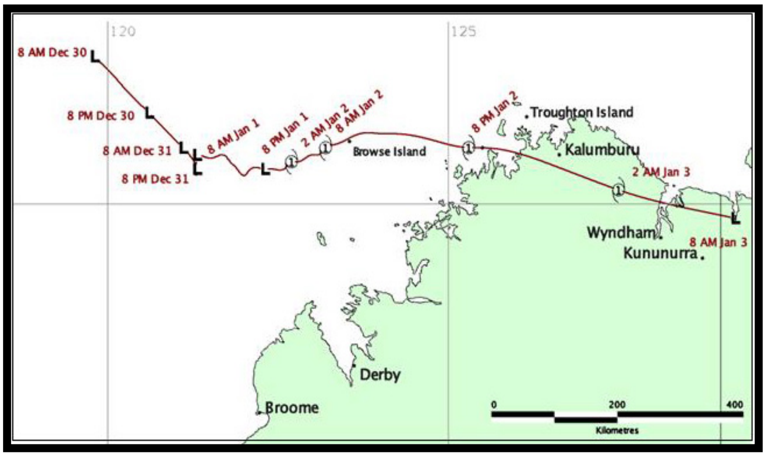
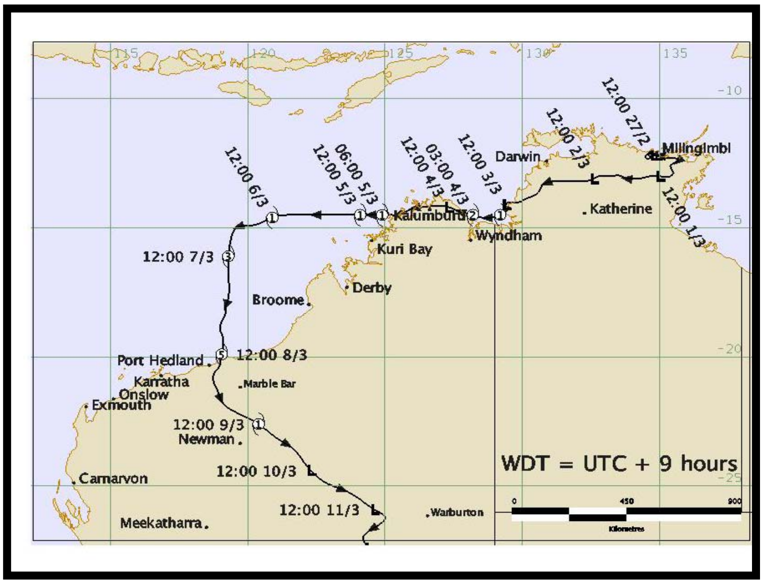


Fig. 3 Track of Tropical Cyclone George in 2007.



1.2 Coral Demography

Monitoring programs of coral reefs have traditionally quantified temporal changes in benthic cover as an indication of health, with high or increasing coral cover regarded as indicative of a healthy reef (e.g. (Oliver et al. 1995). However, to adequately manage coral reefs it is necessary to know how and *why* coral cover changes through time (Hughes 1996; Connell 1997; Bellwood et al. 2004). This requires an understanding of population demography (structure and dynamics) through the collection of complimentary data, which also enables inferences to be made about the future consequences of observed changes. Ideally, the number of individuals of different size-classes (population structure) is quantified through time, in addition to the rates of recruitment, growth and survival (vital rates) that underlie population structure (Caswell 1989; Ebert 1999). These data can then be incorporated into simple matrix models to provide a measure of population health (growth rate), and to project future changes under a variety of physical and biological conditions (e.g. (Done 1987; Fong and Glynn 1998; Fong and Glynn 2000).

To provide insights into demographic causes of changes in coral cover and community structure at Scott Reef, relative to disturbance regimes, the vital rates of populations were quantified for two species of coral with contrasting life histories. *Acropora spicifiera* and *Goniastrea sp.* were chosen because they are abundant at Scott Reef and have contrasting life histories that are characteristic of species with corymbose and massive growth forms, respectively. Several hundred colonies of each species were tagged at sites across Scott Reef, and their rates of growth and survival quantified for different colony size classes. The rates of recruitment and size-structure of colonies within study sites were also quantified. In addition to providing insights into the causes of observed changes in coral cover for the different groups of corals, these data will be combined in simple matrix models that provide estimates of the relative 'health' of each population, the relative importance of different colonies to population maintenance, and the likely changes in population structure in the future under a range of hypothetical disturbances regimes.

1.3 Genetic Connectivity

The current lack of spatially and temporally explicit knowledge of dispersal represents the most critical scientific gap in the understanding required for the effective management of marine systems (Gerber et al. 2003; Sale et al. 2005). In the Timor Sea in northwest of Australia, this knowledge gap is particularly limited. Although long-distance transport of larvae among the isolated coral reef systems in this region seems feasible based on coarse calculations of mean current speeds and pelagic larval durations, considerable evidence from studies elsewhere indicates that larvae of many marine species self-recruit to their source populations (Jones et al. 1999; Swearer et al. 1999; Cowen et al. 2000; Swearer et al. 2002; Largier 2003; Taylor and Hellberg 2003; Jones et al. 2005; Johnson and Black 2006; Almany et al. 2007; Gerlach et al. 2007).

A previous study on hard corals showed that recruitment to Scott Reef and Rowley Shoals is predominantly local (Underwood et al. 2007; Underwood et al. in press). Significant genetic subdivision for both species between systems (>100 km), and between (>10 km) or within reefs (<10 km), indicated that many reefs or reef patches are demographically independent for both a brooding and broadcast spawning coral. Because these patterns of genetic structure were not only strong, but were also consistent between the two species of corals that differed in reproductive mode, these results are likely to be applicable to many hard corals in this region. The primary implication is that short-term recovery of these coral communities after severe disturbance requires the input of larvae from viable communities that are kilometres to a few tens of kilometres away. In addition, genetic divergence in the broadcast spawner between the coastal (Dampier Archipelago and Ningaloo Reef) and offshore (Scott Reef and Rowley Shoals) zones cannot be adequately explained by geographic distance, indicating that transport of larvae between these zones via large-scale oceanic currents is rare even over multiple generations (Underwood in revision). These results also suggest that the coastal and offshore coral systems of northwest Australia will have to rely on their own genetic diversity to adapt to environmental change in the next few decades to centuries.

In contrast to coral larvae, fish larvae have more developed swimming and sensory capabilities, and it is unknown how this will affect their scales of routine and rare dispersal. Therefore the extent of genetic and demographic connectivity in two species of coral reef fish within and among the isolated systems of northwest Australia is being investigated. This will involve an assessment of the ways in which the different life history and behavioural characteristics of these two fish influence their dispersal parameters. The secondary objective is to compare and contrast these patterns with the corals, and utilising the oceanographic and ecological data from other Scott Reef projects, develop a multidisciplinary model of connectivity within and beyond Scott Reef.

1.4 Coral Reproduction and Recruitment

Many species of Indo-Pacific corals participate in mass spawning or multi-specific spawning events that involve the synchronous release of their gametes over a few nights each year (Harrison and Wallace 1990; Baird et al. 2000; Guest et al. 2002; Carroll et al. 2006; Mangubhai and Harrison 2006; Nozawa et al. 2006). On reefs around Australia, most research into broadcast-spawning corals was initially conducted on the Great Barrier Reef where many corals spawn their gametes over a few consecutive nights each year (Harrison et al. 1984; Willis et al. 1985). Synchronous spawning was subsequently reported for reefs off Western Australia (Simpson 1991; Babcock et al. 1994), and further studies identified more species participating in mass spawning events. However, further studies also indentified differences in the times of spawning on in- and offshore reefs and the tendency for 'split-spawning' to occur over consecutive months during some years (Harrison et al. 1984; Willis et al. 1985; Simpson 1991). In addition, quantification of cycles of gametogenesis in an increasing number of colonies and species provided evidence of spawning at times other than during the main nights of mass spawning, over a more protracted period, and more than once a year in a few species (e.g., (Wallace 1985; Harrison and Wallace 1990; Stobart et al. 1992; Wolstenholme 2004).

On the east coast of Australia, coral mass spawning occurs predominately in October and November (Harrison et al. 1984; Willis et al. 1985) with a small proportion of coral species spawning outside of these months (Wolstenholme 2004). On the west coast, mass spawning occurs primarily in March and April (Simpson 1991; Babcock et al. 1994), however recent research has found consistent evidence of biannual spawning at several reefs in north Western Australia (Gilmour et al. 2007b; Rosser and Gilmour 2008). At Scott Reef, mass-spawning occurs predominately in autumn, with a secondary multi-specific spawning event recorded in spring (Gilmour et al. 2007b). The proportion of species and colonies that participate in these two spawning events remains poorly understood and it is unclear whether separate colonies within a species participate in biannual spawning or whether biannual spawning occurs only at the level of the population. Similarly, there is no knowledge of the times of planula release by many common species of brooding corals which are periodically abundant and play a key role in community structure and dynamics.

Future sampling at Scott Reef will quantify the relative participation by colonies and species in the autumn and spring mass-spawning events, and provide insights into the times of planulae production by brooding corals. Information about the times of reproduction for the spawning and brooding corals will also be combined with data on the abundance and cover of different species, to provide estimates of the relative 'significance' of the two mass-spawning periods and of gamete release during other periods of the year.

The potential for coral larvae produced during mass-spawning events to facilitate the recovery of communities following major disturbances is determined by the rates of larval supply, recruitment, and post-recruitment survival. For example, recovery of a community following a disturbance may be slow, even with high rates of larval supply and recruitment, if post-recruitment survival is low; conversely, recovery would also be slow under favourable conditions and high rates of post-recruitment survival, if the rates of larval supply and recruitment are low. Quantifying the importance of recruitment and post-recruitment processes in determining the rates of recovery of coral communities requires a combination of biological and physical data, detailing the magnitude of the disturbance, the degree of connectivity to communities not affected by the disturbance, the changes in physical conditions, and the vital rates of the communities after the event (e.g. recruitment, growth, survival). However, insights into the relative importance of recruitment and post-recruitment processes can be obtained by simultaneously quantifying variation in coral cover and recruitment over different spatial scales; doing so also provides greater understanding of observed rates of recovery for communities, and the extent to which the reefs are 'self-seeded' and reliant on surviving individuals to restock communities.

Changes in coral cover and rates of coral recruitment have been quantified across Scott Reef over ten years, through a series of disturbances regimes. Most notably, there were large and comparable decreases in coral cover and recruitment across Scott Reef following the mass-bleaching event in 1998, and changes in cover and recruitment though cyclone disturbances were weakly correlated at the scale of individual locations. The data indicate that the Scott Reef system is largely self-seeded, and that even over distances of a few tens of kilometres coral communities rely heavily on the local abundance of adults for the supply of recruits; these conclusion are supported by studies of larval ecology (Gilmour et al. in press) and genetics (Underwood et al. 2008).

Because the Scott Reef system is largely self-seeded and the mass-bleaching (1998) reduced coral cover by approximately 80%, the rates of coral recruitment over six years (<2004) after the bleaching had been very low (Gilmour et al. 2006). However, more than six years after the bleaching many of the colonies that recruited to communities are expected to rapidly increase in size (volume), become reproductive, and produce coral recruits. Thus coral cover and recruitment are expected to increase rapidly, and further sampling has been conducted to quantify this relationship. Additionally, further changes in coral cover and rates of recruitment provide more data to investigate the spatial scales at which coral cover and recruitment are correlated, providing better insights into patterns of larval dispersal and connectivity within the Scott Reef system.

1.5 Deep Water Communities

The South Scott Reef lagoon is dominated by extensive areas of high cover coral communities at depths of 30-70 metres. These deep water communities are ecologically significant as they represent a large proportion of the known deep water coral reefs in the Australian North-West Marine Bioregion. The deep water coral communities at Scott Reef are also significant in providing two new taxonomic records for Australia and two new records for Western Australia. In addition, the deep water assemblages may represent potential refugia for the maintenance of the shallow water communities at Scott Reef that are impacted by disturbances, including the effects of tropical cyclones and warm water coral bleaching.

As the deep water habitats at Scott Reef are beyond the limits of scientific diving, a video grab system was developed to document the deep water coral communities. The video grab system allowed highly targeted, minimal-impact sampling of the benthos, and successfully collected coral specimens from the deep water habitats for laboratory analysis.

2 Materials and Methods

2.1 Long Term Monitoring

Benthic communities

In 1994, a long-term benthic monitoring program was established to assess spatial and temporal changes within reef slope communities across Scott Reef. Eighteen monitoring sites were established along the reef slopes (9 m depth) at six locations (Heyward et al. 1997). Most were located in relatively sheltered areas of low water turbidity and not exposed to oceanic swells; two outer reef locations are exposed to the open ocean (SS1, SS2). Additionally, some of the sheltered locations (ie. SL3, SL4) are likely to be bathed in more oceanic waters than others (SL1, SL2), as a result of their proximity to deepwater passages (Fig. 4). At each location, the three sites were separated by approximately 300 m, and at each site were five permanent 50 m transects, marked at 10 m intervals and separated by approximately 10 m.

To quantify changes in cover of benthic organisms, permanent transects were surveyed annually between 1994 and 2000, and again in 2001, 2004 and 2008. During each survey, a tape was laid along each transect and the substrata filmed using a video camera held at a distance of 30 cm. The video footage was analyzed using a point sampling technique (Ninio et al. 2000), whereby the footage for each transect was paused at 40 regular intervals and the organism or substrata beneath each of five fixed points assigned to a benthic life-form category. The hard and soft corals were identified to genera and divided among growth forms.

Fish Communities

To provide a relative description of the fish communities at Scott Reef, the total number of fish species were summarised from taxonomic surveys of the communities at the reef slope, lagoon and outer-reef margin at the Rowley Shoals, Scott and Ashmore reefs systems (Allen and Russel 1986; Allen 1993; Hutchins et al. 1995; Ceccarelli et al. 2001; WAM 2006). All reef fish within these communities were recorded. Surveys were conducted using a semi-quantitative visual survey method during a 45 minute swim along a zig-zag course of approximately 250m within a depth range of 0 - 12 m. Three different observers carried out complimentary tasks, recording all the observed fish species and the abundance counts for each species during each swim.

To quantify the changes in the fish communities at Scott Reef, permanently marked transects were visited during the same period (October-January) during 12 surveys between 1994 and 2008. During each survey, the abundances of fish species were estimated by visual census along transects of fixed width (Heyward et al. 1995). Two transect sizes were used, with the relatively large and mobile fish species (9 families) surveyed along a 50 metre x 5 metre corridor. Smaller, more site-attached species from the family Pomacentridae were sampled along the same transects using a 50 metre x 1 metre corridor.

Multivariate Analyses of Benthic and Fish Communities

Counts of fishes were summed to site level and converted to densities (number of fish, 250m^{-2}) to account for the difference in transect width for the large mobile versus small sedentary species. The percentage contribution of each of twelve life-form categories was averaged to site level. Thus, for both the fish and benthic databases there were three replicates (sites) for each location, on each sampling occasion (year). For ordination analyses, the density of each fish species and percentage contribution of each life-form category in each replicate were Log$_{10}$ and square-root transformed, respectively. The means of the transformed values for each location and year combination were then calculated and used to construct respective Bray-Curtis similarity matrices, which were subjected to non-metric multidimensional scaling (MDS) ordination (Clarke and Gorley 2006).

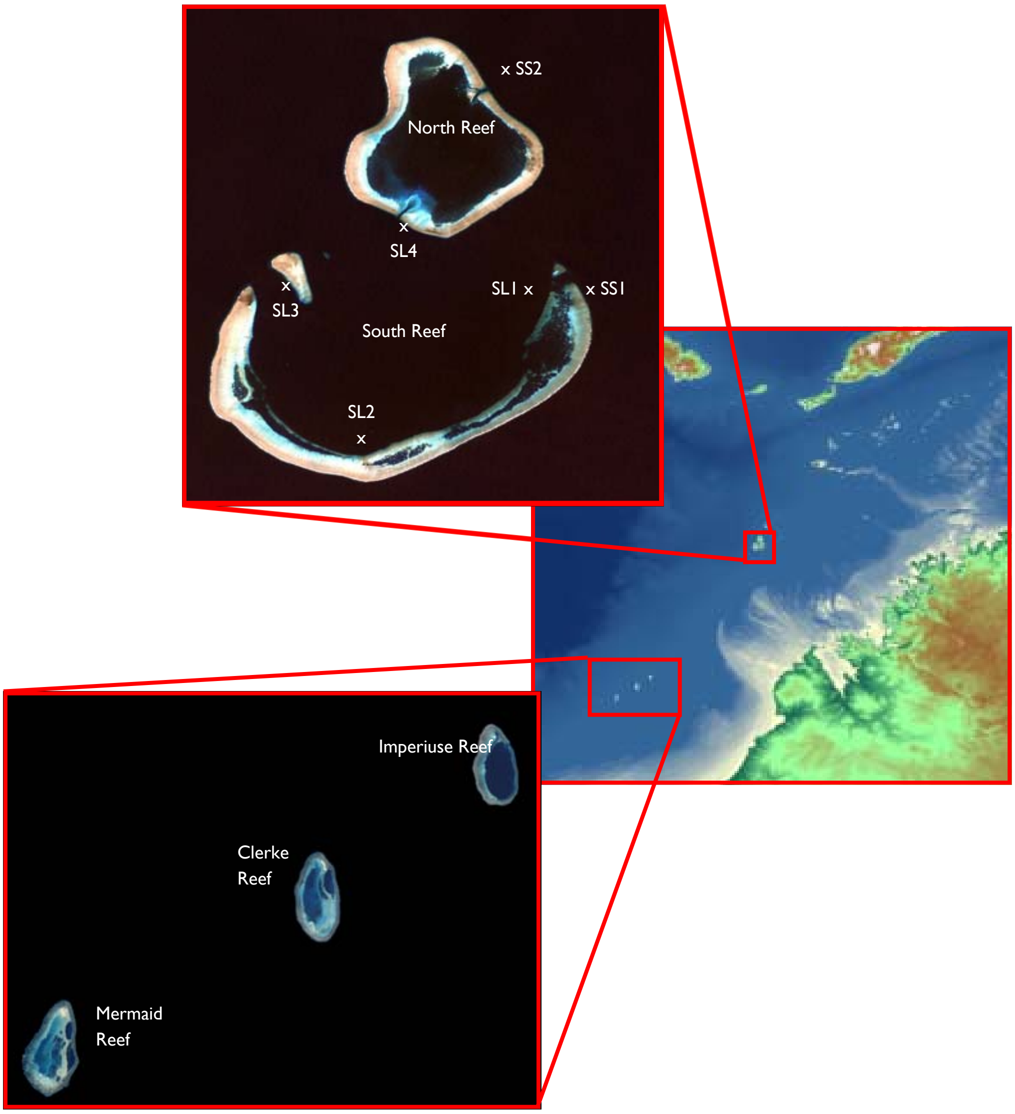


Fig. 4 Study sites at Scott Reef and Rowley Shoals

2.2 Coral Demography

Approximately 1000 colonies of *Acropora spicifiera*, and of two species of *Goniastrea*, were tagged at two sites at four locations (SL1, SL2, SL3 & SL4) across Scott Reef. Colonies of *A. spicifiera* were first tagged in 2006 and colonies from two species of *Goniastrea* first tagged in 2008. Two species of *Goniastrea* were included in the study because the density of any one of the species alone was insufficient for appropriate replication. However, the two species chosen were *Goniastrea edwardsii* and *G. retiformis*, which are closely related, have the same growth forms, and probably very similar life histories. Colonies were surveyed and photographed annually in May or June, yielding information on survival, growth and injury (after colony images have been digitized). Additionally, permanent transects and quadrats were established at each site to quantify the rates of recruitment, population structures and community interactions. At each site at each location, 3 to 4 permanent quadrats and transects were constructed from stainless steel wire and secured to the substrate with push mounts. Each 6 x 3 m quadrat was equally divided with wire into 48 sub-quadrats (75 x 50 cm) and photographed annually. Along the length of each quadrat a permanent transect (30m) was established, within which the size structure of *Acropora spicifiera* and the two species of *Goniastrea* are quantified within a width of 50cm for colonies < 10 cm length, and a width of 200 cm for colonies > 10cm in length. The percentage cover of benthic organisms along the permanent transect will also be quantified using the standard long-term monitoring methods.

The mean rates of recruitment, growth and survival of colonies for populations (vital rates) will be combined in simple matrix models to produces estimates of population health and the importance of different sized colonies to population maintenance, under different levels of disturbances (sites and years). The vital rates of different populations will be combined with their size-structures to project likely changes in population size and percentage cover in the future, and to infer the likely recovery times (resilience) following different disturbances. Community interactions among dominant benthic organisms and study species within permanent quadrats will be interpreted relative to the population dynamics and used to supplement the results of demographic and long-term monitoring data.

2.3 Genetic Connectivity of Coral and Fish

There are extensive practical difficulties involved with tracing movements of large numbers of small propagules with high mortality rates throughout the wide expanses of the pelagic environment. As a consequence, there is absence of direct, empirical data detailing patterns of larval dispersal or retention, and most dispersal studies have utilised a range of indirect, interpretative and aggregative methods (Swearer et al. 2002). Genetic studies on larval dispersal have important practical and theoretical advantages over other methods, and have been consistently employed to explore these questions since the advent of molecular markers. These methods utilise the inherent differences in the DNA sequences of individual genomes that accumulate through selection or drift when gene flow is restricted. Well-developed theoretical models utilise either gene frequencies (e.g. allozyme and microsatellite data), or genealogical relationships of specific DNA sequences (e.g. mitochondrial DNA sequences), to measure the spatial distribution of genetic variation, allowing assessment of the genetic similarity of populations and subpopulations (Hellburg et al. 2002). This allows for estimates of genetic mixing, and thus provides an effective method to investigate the influence of dispersal and subsequent recruitment on the distribution of molecular variants (Palumbi 2003).

There are many different molecular tools that can be applied for maximum benefit to different biological questions (Sunnucks 2000). Microsatellite markers, which consist of tandemly repeated nucleotide sequences, have several attributes that make them most suitable for ecological studies (Estoup and Angers 1998). Between 30 and 60 specimens from at least six sites from each of Scott Reef and Rowley Shoals will be genotyped with microsatellites. Population differentiation and levels of gene flow within and among reefs will be calculated in an AMOVA framework. A model-based clustering method will be used to infer the most likely number of populations in the data set. If the level of population division is sufficiently large, recent migrants will be identified using assignment and exclusions tests. In addition to microsatellites, mitochondrial DNA (mtDNA) markers will also be utilised in the fish study to compliment the microsatellite data. mtDNA is useful for delineating evolutionary significant units and management units, (Moritz 1994) as well as reconstructing past demographic processes (for example bottlenecks, population size expansions).

Two study species that differ in life histories and behaviour are being studied. *Chromis margeritifer* is a common pomacentrid that lives in close association with live branching corals and is more abundant in exposed slope habitats. This species lays demersal eggs and once hatched, larvae live in the pelagic environment for between 30 and 36 days. This mode of reproduction is common, and the pelagic larval duration is relatively high for fish species that associate with live coral. Therefore, *C. margeritifer* will provide a good representation of many coral reef fish that have a relatively high potential for long-distance dispersal. *Cheilodipterus artus* is a common apogonid cardinal fish which broods its eggs in its mouth before releasing larvae into the water column for duration of about three weeks. These apogonids live in much more sheltered water in lagoons, congregate in schools under reef overhangs, and are patchier in their distribution compared with *C. margeritifer*. In addition, adults have strong homing behaviour to their diurnal resting sites (Marnane 2000). Therefore, this apogon is likely to be representative of those coral reef fish with limited dispersal potential, and levels of genetic subdivision are likely to be greater for *C. artus* compared with *C. margeritifer*. The only relevant study conducted so far supports this hypothesis, and suggested that swimming speed and behavioural ability to home to natal sites may differ between these fish (Gerlach et al. 2007).

2.4 Coral Reproduction and Recruitment

Pre-Spawning Visual Survey

The reproductive state of corals at Scott Reef was assessed by *in situ* visual examination of gamete development at five locations (SL1, SL2, SL3, SL4, SS2). Replicate colonies of the dominant spawning and brooding corals were sampled in February 2008, prior to the predicted major spawning in autumn.

Colonies were randomly selected adjacent to the long term monitoring transects, identified to species, and then fractured to allow visual examination of eggs within the polyps. Only large colonies (> 20 cm) were examined to ensure that colonies were sexually mature. All branches were selected from the colony centre to avoid the sterile, actively growing colony margins. For each colony, reproductive state (egg presence and colour) was scored for three fragments and used to infer predicted spawning times. Colonies were scored according to the following criteria:

Score 1	Large pigmented (red or pink) eggs were clearly visible within polyps, indicating that colonies will spawn following the next full moon, and within one month;
Score 1/2	Unresolved egg state (between states 1 and 2) indicating that colonies will spawn following the next full moon or two full moons, and within one or two months;
Score 2	Large unpigmented (white or cream) eggs were clearly visible within polyps, indicating colonies will spawn following two full moons and within two months;
Score 3	Small unpigmented (white or cream) eggs were visible within polyps, indicating colonies are unlikely to spawn for several months;
Score 4	No eggs were visible within polyps, indicating that colonies had recently spawned, or will not spawn for many months.

Pre-Spawning Sampling Survey

Adjacent to the permanent quadrats, replicate colonies of *Acropora spicifera* were photographed *in situ*, before a minimum of three branch fragments were collected from the central region of each colony. Fragments of other *Acropora* and non-*Acropora* species were also collected for laboratory analyses. Additional samples were collected from deepwater locations (>30m) with a Van Veen grab to enable preliminary comparison of reproductive ecology between shallow and deep water species.

All specimens were fixed in 10% formalin & seawater, then decalcified using a progressive protocol of increasingly concentrated hydrochloric acid (3-4 days at 1% HCL, 3-4 days at 5% HCL, 2-3 weeks at 10% HCL). After decalcification, specimens were transferred to 70% ethanol for analysis and long term storage.

From each decalcified colony, five polyps were randomly selected from each of the three branches and dissected under a Leica MS205 stereo microscope to derive estimates of fecundity and egg size. Oocyte maximal and medial diameters were measured using Leica Application Suite version 3.1 software, and the geometric mean for each oocyte was calculated as the square root of the maximal x medial diameter. Polyp fecundity was recorded as the number of oocytes per polyp.

Post-Spawning Rapid Visual Assessment

In early April 2008, several weeks prior to the predicted late April spawning period, a rapid visual assessment of the reproductive state of scleractinian corals was conducted at Scott Reef alongside the Surface Supply Breathing Apparatus (SSBA) study. Survey methodology utilised the pre-spawning visual survey technique but was limited to three study locations.

Future Data Analysis

Further sampling will occur prior to the major spawning period in October / November 2008. Future data analyses will determine the size at sexual maturity of *A. spicifera* by scoring gamete development in small size class colonies. Size at sexual maturity and size-specific fecundity will be determined by correlation of colony dimensions with fecundity per cm^2.

Size frequency distributions of target species will be determined from digital photography taken of the sampling area (photographs taken at one metre intervals). Colony dimensions will be calculated using Image J software Version 1.38. Random point count software will be used to determine the percentage cover and relative contributions of target species to the community assemblage. Estimates of the total proportion of corals that participate in the mass-spawning events will be derived from the combination of reproductive data and percentage cover of sampled colonies. Histological analyses on the brooding corals *Acropora palifera, A. brueggemanni,* and *Seriatopora hystrix* will be utilised to examine cycles of gametogenesis and planula development.

Larval supply and recruitment of corals

The rates of larval supply and recruitment of corals at Scott Reef were quantified from 1996 to 1999, and in 2002, 2003, 2006 and 2008, at six monitoring locations (SL1, SL2, SL3, SL4, SS1& SS2). At each of the locations, six terracotta settlement plates (110mm x 110mm x 10mm) were deployed at each of the three sites separated by 50 m on the reef slope (18 plates location^{-1} year^{-1}). The six plates were spaced haphazardly, approximately 1 m apart, and attached to the reef (see Mundy 2000) two weeks prior to the predicted mass coral spawning in autumn and collected eight weeks later. After collection, the settlement plates were bleached and the coral recruits counted using a stereo-dissection microscope.

2.5 Physical Data

Water temperature was recorded at six shallow monitoring locations (SL1, SL2, SL3, SL4, SS1 and SS2) at Scott Reef. A single Odyssey water temperature logger was attached to the first star picket (9 m depth) of the first monitoring site at each location. During the initial February field trip, a single logger was sealed in a plastic zip-lock bag before being attached to the star picket with stainless steel wire and cable ties. Each logger was calibrated to continuously log water temperature at 60 minute intervals until subsequent retrieval within a year. Loggers were retrieved from three locations (SL1, SL3, SS2) after they had recorded temperature between March 2007 and April 2008.

Sedimentation rates at Scott Reef were derived from the deployment of sediment traps at four lagoon locations (SL1, SL2, SL3, SL4) and two outer-ref locations (SS1 and SS2). Sediment traps were deployed for two months between February and May 2008 and will be processed on each subsequent sampling occasion. Sediment traps were constructed from hollow cylindrical lengths of PVC plumbing tubing that was 700 mm long with an internal diameter of 110 mm (Fig. 5). The bottom of each trap was sealed with a screw type PVC cap and the internal baffle system at the entrance of each trap was composed of seven 150 mm lengths of PVC tube with an internal diameter of 30 mm, joined together and screwed into the top of the trap so that each baffle sat flush with the outer entrance of the trap (Fig. 5). The baffle system was designed to prevent larger organisms from occupying the traps (e.g. fish, crustaceans and octopus), and therefore prevent their nitrogenous waste products and moult shell from contaminating the sediment load. At each location, 5 sediment traps were secured with stainless steel wire and cable ties to vertically oriented star pickets at 10m intervals along the first transect at the first site at monitoring locations. Each trap was attached to the star picket so the opening was 80 cm above the substrate.

Upon retrieval of the traps, the sediment and water are passed through a 1 mm sieve to remove any large organic material (e.g. fish and crabs). The retained water containing the sediment is mixed thoroughly to homogenise the sample and four 60 ml replicate sub-samples are extracted with a syringe and vacuum filtered through pre-weighed (5 decimal places) polycarbonate 0.4 µm membrane filters (Fig. 6). Each filter was then placed in a labelled petri-dish and transported to the laboratory frozen. Petri-dishes were placed in an oven overnight at 60˚C and then cooled in a dessicator unit before re-weighing the filter to determine the dry weight of sediment (mg). The rate of sediment deposition (mg cm^{-2} d^{-1}) for each sub-sample was calculated using the weight and volume of water sampled, area of the entrance of the trap and the number of days the trap was deployed.

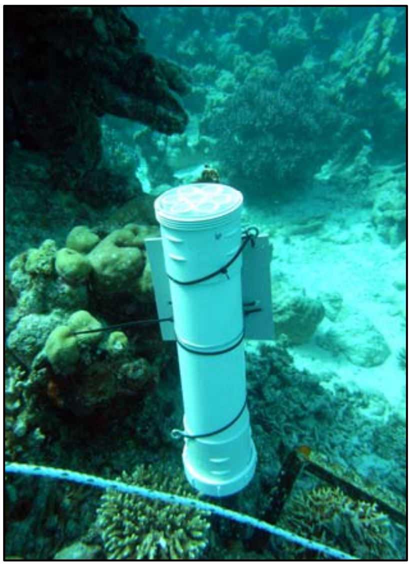


Fig. 5 Sediment trap attached to star picket

Fig. 6 Sediment filtration manifold

2.6 Deep Water Communities

To investigate the deep-water coral communities in the south Scott lagoon, a low-light video camera with live feed was mounted above a Van Veen benthic grab. The video grab was deployed in February 2008 at 69 sites at South Scott lagoon, which ranged in depth from 30-70m (Fig. 7). Sampling sites were selected both randomly and in a stratified design to capture a range of deep water habitats. The video grab system enabled accurate, small-scale sampling of specific coral colonies and the capture of digital images of the deep water coral communities.

Colony samples obtained using the grab were preserved for taxonomic, histological, and genetic analyses. Taxonomic specimens were preserved in bleach (calcium hypochlorite 700g/kg; 250g per 10 litres), then dried, wrapped in paper, and transported to the laboratory. Reproductive specimens were preserved in 10% formalin & seawater, and will be processed according to the protocol developed for shallow water coral samples or using histology techniques. Genetic specimens were preserved in alcohol (99.6% analytical grade) and stored in scintillating vials for future analyses.

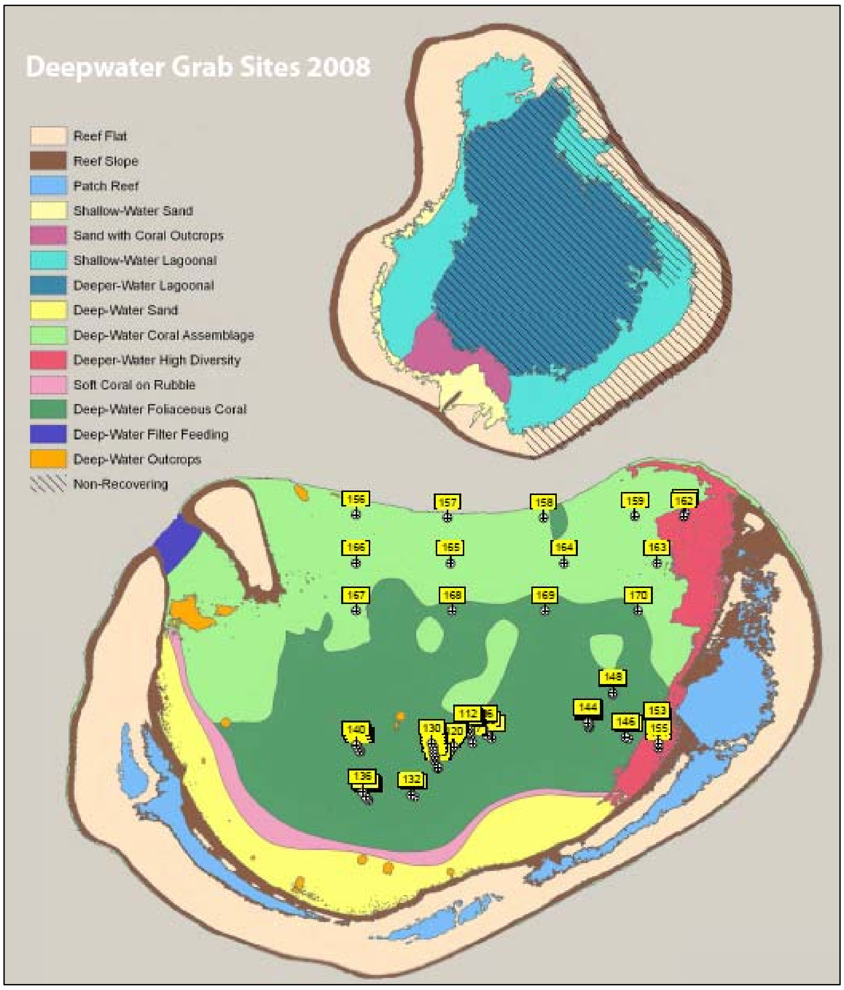


Fig. 7 Deep water grab sites at South Scott lagoon in 2008.

3 Results and Discussion

3.1 Long Term Monitoring

Benthic communities: hard and soft corals

The cover of hard corals at Scott Reef is now similar to that prior to the bleaching (1997), although the cover of soft corals remains at approximately half that prior to the bleaching. On average, the total cover (± S.E.) of hard corals in 2008 was 37% (± 1), compared to 42% (± 2) in 1997, whereas the cover of soft corals was 4% (± 1), well below that (8% ± 1) in 1997 (Fig. 8).

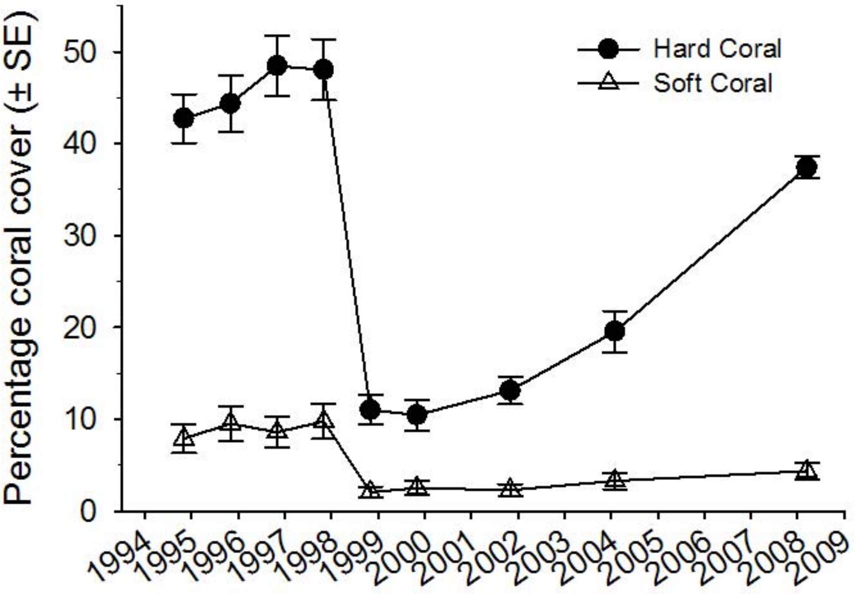


Fig. 8 Changes in the mean cover of hard and soft corals at all monitoring sites across Scott Reef. Mass-coral bleaching occurred in 1998.

The recovery of hard corals and the changes in cover ten years after the bleaching varied among the locations at Scott Reef (Fig. 9). The initial (1998-2004) increases in coral cover were most rapid at the locations (SL1, SL2, SL3 & SL4) least affected by the bleaching, and slowest at the worst affected locations (SS1 & SS2). However, in more recent years (2004-2008) there was a different pattern of variation; the locations with the fastest (SL1, SL2, SS1& SS2) or slowest (SL3 & SL4) increases in cover differed from those shortly after the bleaching (Fig. 9).

Different patterns of change among the locations ten years after the bleaching reflect their different community structures, rates of larval supply and exposures to cyclones. The impact of cyclones on coral communities at Scott Reef varied according to their exposure to the resulting winds and waves. In 2004, Category 5 Cyclone Fay passed directly over Scott Reef, and there were subsequent decreases in mean coral cover at locations SL2, SS1 and SS2 (Fig. 9). Two years later (2006), Cyclone George passed to the south of Scott Reef, again having a variable impact on the coral communities; the smaller relative increases in coral cover at locations SL3 and SL4 between 2004 and 2008 were probably due to the impacts of Cyclone George, which is supported by the patterns of growth and survival of tagged colonies.

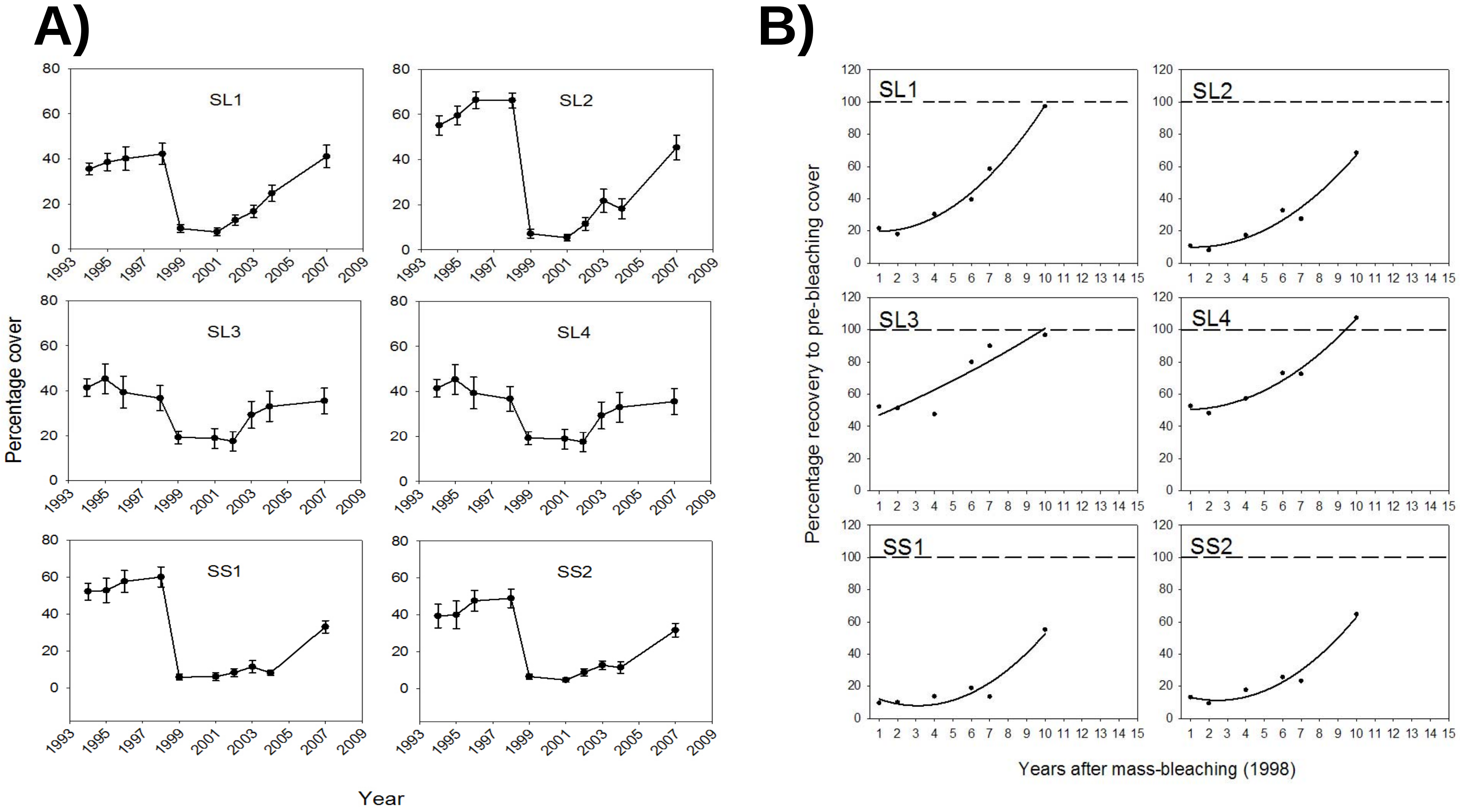


Fig. 9 Absolute changes in percentage cover of hard corals at locations across Scott Reef; the bleaching occurred in 1998, Cyclone Fay in 2004 and Cyclone George in 2006. B) Percentage recovery of hard coral cover to pre-bleaching levels (1997) through time at locations across Scott Reef; recovery is at 100% when mean coral cover is that same as that prior to the bleaching in 1997.

Cyclone disturbances at Scott Reef had more localised and heterogeneous impacts on coral communities than did the temperature induced mass-bleaching in 1998, which caused massive decreases in coral cover across the entire reef system. Indeed, throughout the cycles of cyclone disturbance, the mass-bleaching remains the most influential event determining the current cover of hard corals at Scott Reef; the locations (SL2, SS1, SS2) with the greatest absolute and relative decreases following the bleaching had not returned to their pre-bleaching cover in 2008, whereas the least affected locations (SL1, SL3, SL4) had returned to a similar or greater coral cover (Fig. 9). These changes in coral cover reflect the extent to which disturbances that occurred many years ago can influence the current structure of coral communities (Hughes 1989).

Benthic communities: families of hard coral

The dominant families of hard coral displayed different patterns of impact and recovery from the mass-bleaching in 1998, but ten years later their relative abundances were approaching those prior to the disturbance (Fig. 10). Prior to the bleaching (1997), the family with the highest mean coral cover (± S.E.) was the Acroporidae (27% ± 5), followed by the Poritidae (10% ± 1) and Pocilloporidae (4% ± 1). Following the bleaching, the Acroporidae and Pocilloporidae had the largest relative (>80%) decreases in cover, compared to a smaller (56%) relative decrease for the Poritidae; the Acroporidae and Pocilloporidae were also initially slow to recover, with little increase in cover three years later, while there were larger relative increases in the cover of the Poritidae over the same period (Fig. 10). The Poritidae were least susceptible to the bleaching because many colonies suffered partial- rather than whole-colony mortality and the re-growth of survivors resulted in the initial increases in cover (Brown and Suharsono 1990; Loya et al. 2001).

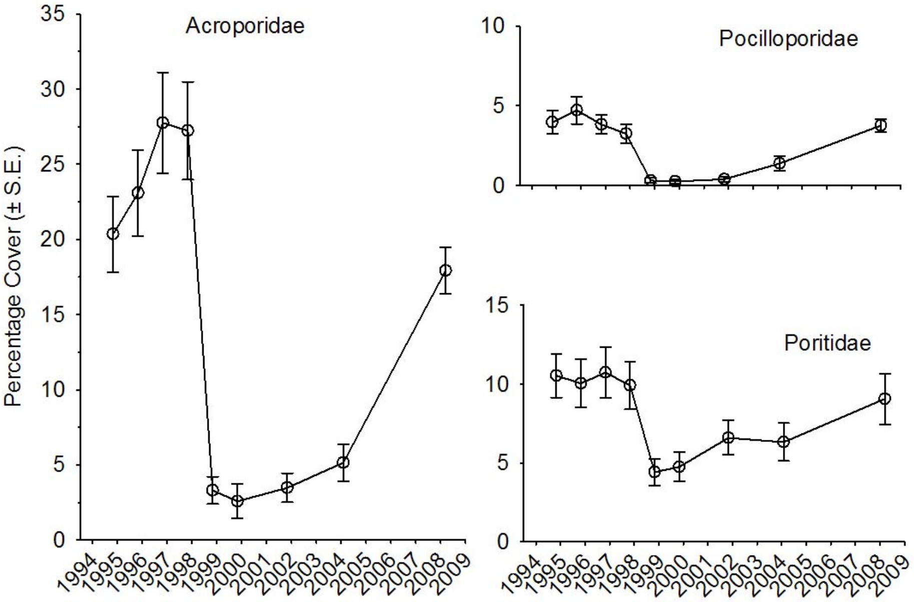


Fig. 10 Changes in the mean cover of the dominant families of hard corals at all monitoring sites across Scott Reef. Mass-coral bleaching occurred in 1998.

More than three years after the bleaching the increases in cover were more rapid for the Acroporidae than for the Pocilloporidae and Poritidae (Fig. 10). By 2008, the mean cover of the Acroporidae and Pocilloporidae had increased to 18% (± 2) and 4% (± 1) respectively, whereas the Poritidae had increased in mean cover to 9% (± 2). Ten years after the bleaching, the cover of Acroporidae had returned to 65% of that prior to the bleaching, whereas the cover of the Poritidae and Pocilloporidae was similar or greater than (>90%) that prior to the bleaching. The more recent changes in the cover of the Acroporidae and Pocilloporidae provide examples of how the recovery of these families from major disturbances can accelerate through time, due to comparatively high recruitment and rapid growth (Harrison and Wallace 1990; Halford et al. 2004). Additionally, the ability of the Acroporidae to outcompete (overtop) other species of corals, such as those in the families Poritidae and Pocilloporidae, means they are expected to again become the dominant coral across the Scott Reef system in the absence of additional disturbances.

Benthic communities: community structure

Following the 1998 mass-bleaching, the cover of all benthic groups decreased by at least a half (hard corals, soft corals, sponges), with the exception of the turfing and coralline algae that increased in cover (±S.E.) from 37% (±2) in the years prior to the bleaching to 75% (± 4) the year after (Fig. 11). The colonisation of available space by algae following the bleaching did not include the fleshy macroalgae, whose cover was < 1% at all locations both before and after the bleaching. Changes in the relative abundances of the Acroporidae, Poritidae and Faviidae drove the structural changes in the hard coral communities at different sites, from communities previously dominated by branching *Acropora* (47%) and other branching corals (9%), to communities with a lower coral cover in which massive corals had the highest (45%) relative abundance (Fig. 11). Indeed, it was the sites with the highest cover of branching corals that were worst affected by the bleaching and underwent the largest changes in community structure.

In 2004 there had been few changes in the benthic community at Scott Reef. Turfing and coralline algae remained the dominant benthic group at all locations (Fig. 11), with a mean (±S.E.) cover of 65% (± 4), and the mean (±S.E.) cover of soft corals (3% ± 1) and sponges (<1%) remained low. The relative decreases in the cover of algae since the bleaching were however matched by increases in coral cover, which were similar for the branching *Acropora* (2%), other branching corals (1%), and tabulate (1%), foliaceous (1%) and massive (3%) corals. Consequently, the branching *Acropora* had returned to only 21% of its previous cover, whereas the massive corals and tabulate corals had returned to 59 and 100% of their previous cover, respectively; the other groups had returned to between 30 and 40% of their previous cover (Fig. 11).

Ten years after the bleaching benthic communities continued to return to their previous structure, but the cover of turfing and coralline algae was still higher than that prior to the bleaching and there was an increased cover of tabulate corals and sponges. Turfing and coralline algae remained the dominant benthic group at all sites (Fig. 11), with a mean (±S.E.) cover of 43% (± 2). Following small increases between 2004 and 2008, the mean (±S.E.) cover of soft corals (4% ± 1) remained low, having returned to approximately half (52%) the cover prior to the bleaching. Similarly, there were small increases and decreases in the cover of branching *Acropora* and other branching corals at sites across Scott Reef (Fig. 11), to a mean (±S.E.) cover of between 2 and 3% (±1); the cover of branching *Acropora* and other branching corals had returned to 25% and 47% of that prior to the bleaching, respectively. The massive corals (e.g. Poritidae, Faviidae) continued to increase in cover at some sites, but with small decreases at other sites; on average, the mean (±S.E.) cover of massive corals had reached 10% (±2), which was approximately 60% of that prior to the bleaching. Of all benthic groups, the most notable changes between 2004 and 2008 were the increases in cover of tabulate corals and sponges (Fig. 11). Tabulate corals were largely composed of species of *Acropora* with table or corymbose growth forms, and had increased at most sites to a mean (±S.E.)

cover of 5% (±1), compared to <1% prior to the bleaching. Sponges also had large relative increases in cover at most sites, to a mean cover of 3% (±1), compared to <1% prior to the bleaching.

As with the changes in the total cover of hard corals, the changes in the cover of growth forms reflected the exposure of sites to the different regimes of disturbance. For example, the small changes in the abundance of branching corals and the large increases in the abundance of tabulate corals in recent years (>2004) may reflect a combination of successional recovery following the bleaching and the local impacts of cyclone disturbance. At most of the sites least affected by the bleaching, the cover of branching corals had decreased in recent years, rather than the further increases that were expected. However, these sites (e.g. locations SL3, SL4) were also among those most exposed to recent (2006) cyclone disturbances that impact branching corals; the increases in the cover of massive corals over the same period were also largest at these sites (Fig. 11). In contrast, the largest increases in the cover of the tabulate corals and sponges were at the sites worst affected by the bleaching, where the decreases in the cover of branching corals were most significant. Thus, the increases in the cover of tabulate corals may reflect the successional changes in the community structure following major disturbances; with few branching *Acropora* and branching corals surviving the bleaching, recruitment may have been dominated by the tabulate growth forms which occupied the available space. In the absence of further disturbances, however, the abundances of branching corals would be expected to increase, due to their high rates of growth, local recruitment, and ability to outcompete other corals or sponges. Such successional changes in the cover of branching corals are exemplified by the brooding coral *Acropora bruegmanni*, which was the dominant species prior to the bleaching. *A. bruegmanni* is particularly susceptible to disturbances such as elevated water temperatures and cyclones, but has very high rates of growth and local recruitment, and is capable of crowding and overtopping other benthic organisms. The extent to which branching corals again dominate at many sites across Scott Reef, and the benthic communities return to their previous cover and structure, depends on the regimes of disturbance in the future. In particular, the frequency and severity of cyclone disturbances and whether communities are again exposed to extreme water temperatures arising from climate change.

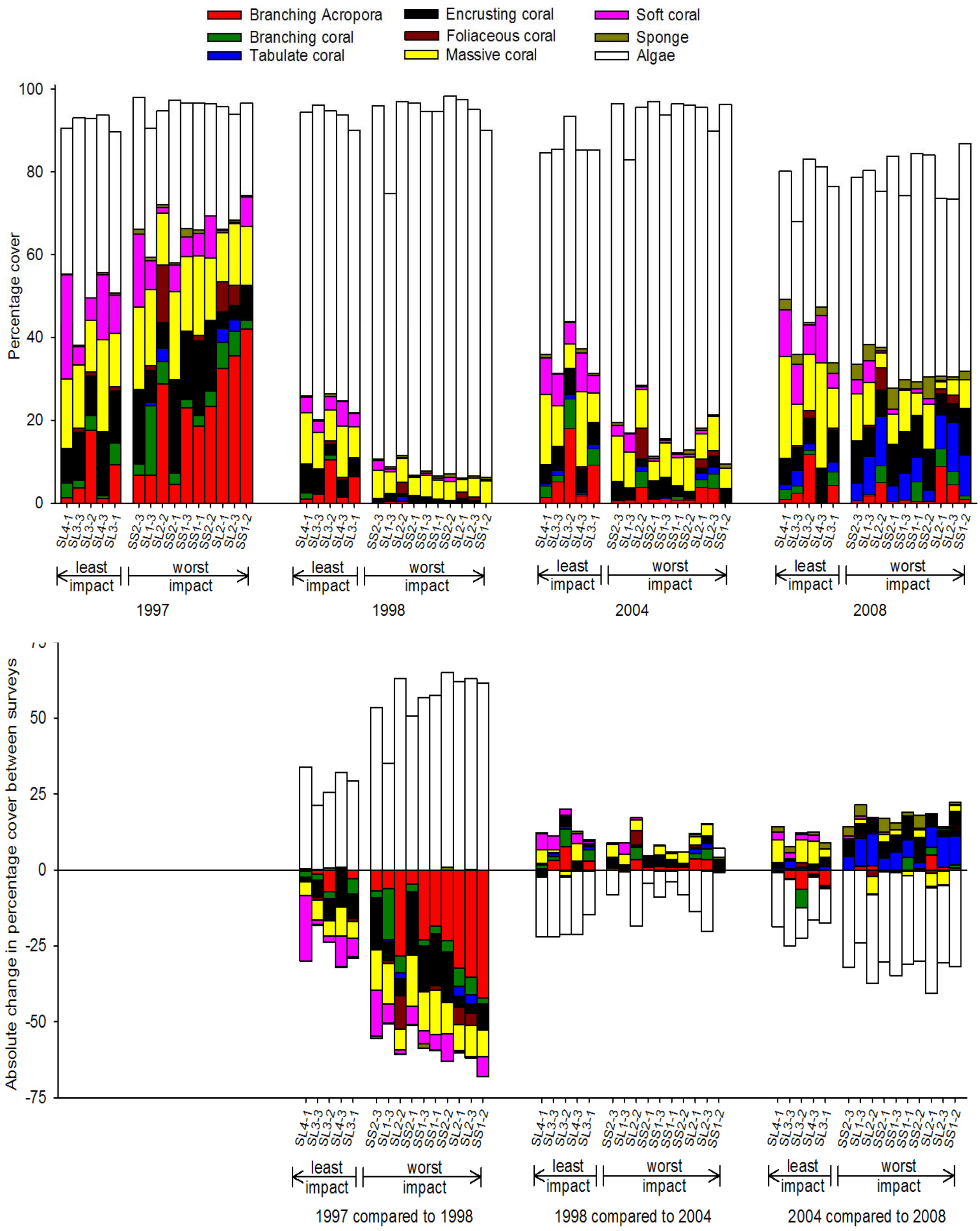


Fig. 11 Temporal variation in percentage cover of benthic groups at sites at Scott Reef; Algae group is predominantly turfing and coralline algae, and not macroalgae. Sites are in order of increasing impact following the bleaching. B) Absolute changes in percentage cover of benthic groups at sites between selected surveys: 1997 compared to 1998; 1998 compared to 2004; 2004 compared to 2008.

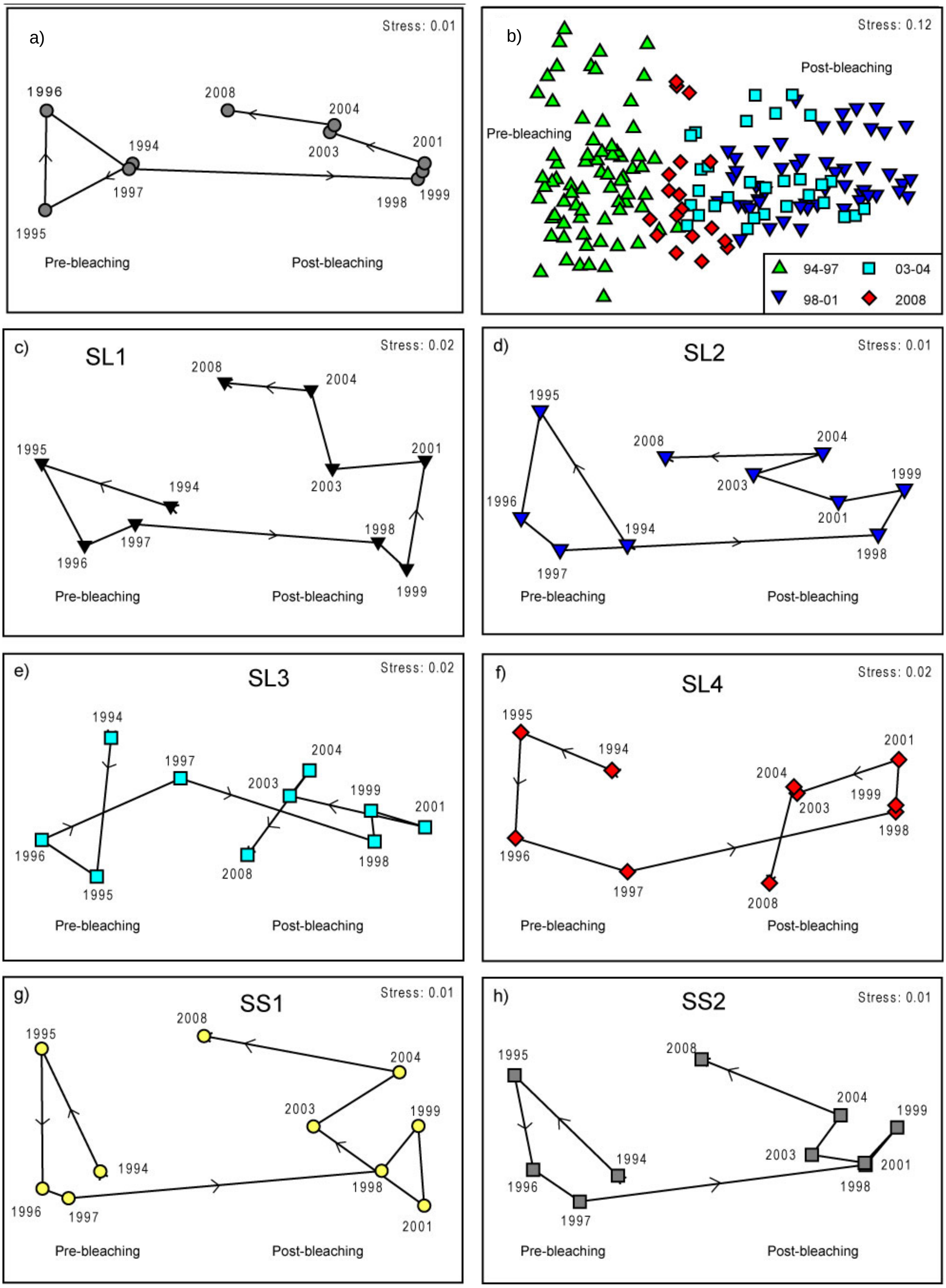


Fig. 12 Non-metric multidimensional scaling (nMDS) ordinations of the compositions of benthic assemblages at Scott Reef between 1994 and 2008. Ordinations for (a) the benthic composition in each year averaged across all locations (b) for all samples coded for year group and (c to h) for each of the six locations separately.

Multivariate analyses of the twelve dominant benthic groups (see Fig. 11) clearly illustrated the mean pattern of disturbance and recovery for communities across all of Scott Reef. In particular, the impact of bleaching in 1998, the slow initial return of community structure towards the pre-bleaching state, the delay in recovery due to the impacts of Cyclone Fay in 2004, and the ongoing recovery towards a pre-bleaching structure in 2008 (Fig. 12 a). A similar pattern was evident at all locations across Scott Reef, with locations grouping together according to the different periods of impact and recovery (Fig. 12 b). However, community structure differed significantly both among years and among locations (Two-way ANOSIM; *P*=01%). Indeed, the magnitude of variation in cover of benthic groups (Global *R* statistic) was similar among years (0.887) and locations (0.897), because of the initial differences in community structure among the locations and their differing patterns of impact and recovery from disturbances (e.g. bleaching, cyclones). The differences in patterns of impact and recovery were evident in the trajectories of change for the different locations (Fig 12 b-h), and following the large change in community structure due to the bleaching, were primarily driven by the exposure of locations to cyclone disturbance. The impacts of Cyclone Fay in 2004 on benthic communities varied according to the exposure of the different locations, with locations SL2, SS1 and SS2 being worst effected, then SL3 and SL4, then SL1. Cyclone George in 2006 had less severe and more localised impacts on community structure, slowing the recovery of communities at SL3 and SL4 and causing a side-ways shift in community structure up to 2008, whereas at the other locations the impact was less severe and they displayed a large shift towards the pre-bleaching state up to 2008.

Fish communities

The effects of the 1998 bleaching event and 2004 cyclone were presented in an analysis of 10 years (1994 to 2003) of annual monitoring of fish assemblages at Scott and Seringapatam Reefs (Smith et al. 2004). These results concluded that the fish assemblages at Scott Reef five years after the 1998 bleaching were very different from those prior to the bleaching. The spatial structure of the fish communities was initially maintained and impacts from the bleaching typically lagged by 12 - 18 months. Although there were significant reductions in abundances of species that were heavily dependent on hard coral for food and/or shelter, such as the Chevroned butterflyfish (*Chaetodon trifascialis*), there were increases in abundances of species with a dietary preference for algae, such as the Jewel damselfish (*Plectroglyphidodon lacrymatus*). Species that did not display any marked changes in abundance were often most common at locations least impacted by the bleaching.

Five years after the 1998 coral bleaching, the fish assemblages on five of the seven surveyed locations still differed from their pre-impact structures, although signs of recovery were evident. Such differences in species composition were mainly due to changes in the relative abundances of species within the Chaetodontidae (butterflyfishes) and Pomacentridae (damselfishes), two families whose species exhibit a close association with the benthos. The pattern of recovery of the fish communities are therefore linked to that of the corals, and both are likely to continue to increase to pre-1998 levels in the absence of additional disturbances.

Although the recovery of the coral communities at Scott Reef was slowed by Cyclone Fay in 2004, there was surprisingly little change in the fish communities (Smith et al. 2004). Only species on the exposed sites showed an obvious shift from pre-cyclone community, which was largely due to an increase in several species of damselfish; most significantly, juvenile sized *Chrysiptera rex* and *Pomacentrus philippinus*. The juveniles were too small to include in the January 2004 (pre cyclone) count, so the shift in damselfish may be due to a strong recruitment event prior to the cyclone, rather than any affect of the cyclone. Many of the coral species with a growth form most susceptible to cyclone damage had not recovered from the bleaching. Consequently, the fine scale structure of coral habitats that strongly influences the fish communities had changed little before and after the cyclone, resulting in correspondingly small changes in the fish communities. Had the mass-bleaching not occurred in 1998, then Cyclone Fay would have had a far more dramatic affect on the fish and coral communities at Scott Reef.

The structure of fish communities and their changes through time were quantified at reef slope habitats at Scott Reef during regular surveys from 1995 to 2001 (Gilmour et al. 2007a). The species compositions of communities at Scott Reef differed to those at Rowley Shoals, located 300 km to the south (Fig. 4). The main species responsible for such differences were the damselfish species *Pomacentrus lepidogenys* and *Chrysiptera rex* that were abundant at Scott Reef but absent from the Rowley Shoals. Fish species richness was higher at Scott Reef (721) than at either Ashmore Reef (568) or the Rowley Shoals (569), however, there were slightly more families of fishes at the Rowley Shoals and Ashmore than at Scott Reef (Fig. 13; Appendix 1). Although a recent survey of fishes at the Rowley Shoals and Scott Reef did not add to these numbers (WAM 2006), further surveys at Ashmore Reef may yield additional species for that area.

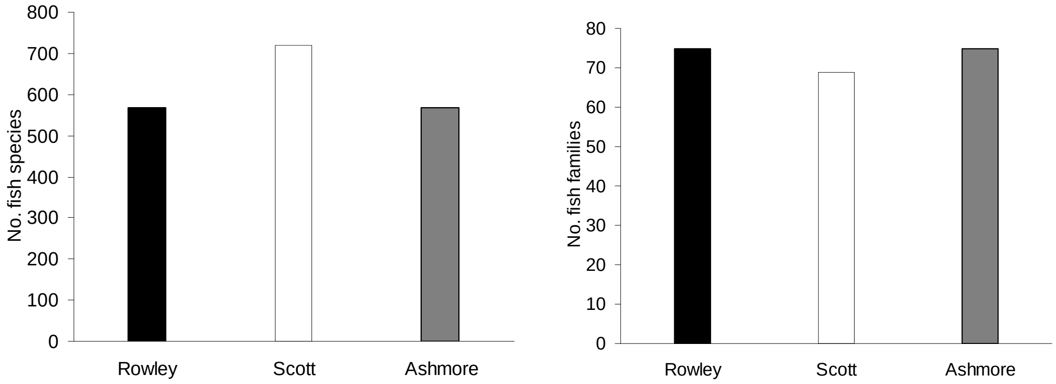


Fig. 13 Total fish species and familial richness at the Rowely Shoals, Scott Reef and Ashmore Reef.

The mean abundances of the family Pomacentridae (damselfishes) demonstrated a sequential decreasing trend between 1995 and 1999, followed by a mainly sequential increase to 2008 (Fig. 14). In contrast, the mean abundances of the large reef fish illustrate a general trend of increasing abundance over time since 1995 (Fig. 15), regardless of the decreases and increases in coral cover following the bleaching. Further sampling of the fish communities and subsequent analyses that take into account the different trophic categories of fish species will lead to a better understanding of the causative factors for the increase in numbers of the larger more mobile fish species over time. Reef fish communities are broadly composed of corallivores, coral dwellers, herbivores, omnivores, invertivores, piscivores and planktivores, all with different resource requirements. Corallivorous fishes can be broadly divided into obligate or facultative corallivores. Obligate species are considered to have a diet consisting of at least 80% coral whereas the level of reliance on coral shown by facultative species varies greatly between individuals and between locations, making it difficult to assess the level of coral dependence for many these species.

On the ordination plot for reef fishes recorded at six locations at Scott Reef between 1994 and 2008, the points representing the samples from each location formed very discrete groups (Fig. 16a). Samples from the most protected location (SL2) formed a group at the bottom of the plot, whereas those from the more exposed locations (SS1, SS2) formed a group at the top. When these samples were coded according to year category, those from the pre-bleaching period lay to the left of the plot and those from the post-bleaching period lay in the middle with those from 2008 forming a group to the right of all earlier samples (Fig. 16b). At the year level, there was a clear separation of the points into a group containing all those from 1994-1999 on the left and all those from subsequent years on the right (Fig. 16c). This pattern was also reflected at each location separately (Fig. 17). Furthermore, the lines overlain on each plot to illustrate sequential change through time, indicate that the fish species composition from 2001 onwards is different to that which occurred prior to 2001, irrespective of location.

These results demonstrate that the fish species composition of Scott Reef has been undergoing change since the 1998 bleaching event and distinct pre- and post-bleaching fish assemblages are apparent. There was a lag in the effect of bleaching on the fish communities, with those shortly after the bleaching being similar to the communities before the bleaching. However, through time the disparity between pre- and post-bleaching observations increased. This situation parallels the results of a study of long-term changes in the cryptobenthic reef fish community at one location on the Great Barrier Reef (Bellwood et al. 2006). It may be relevant that the contribution of tabulate corals at particular locations has been increasing since 1998 and thus certain fish species may benefit in response to such changes in habitat structure.

Fig. 14 Mean abundance values of pomacentrid fishes at Scott reef between 1994 and 2008.

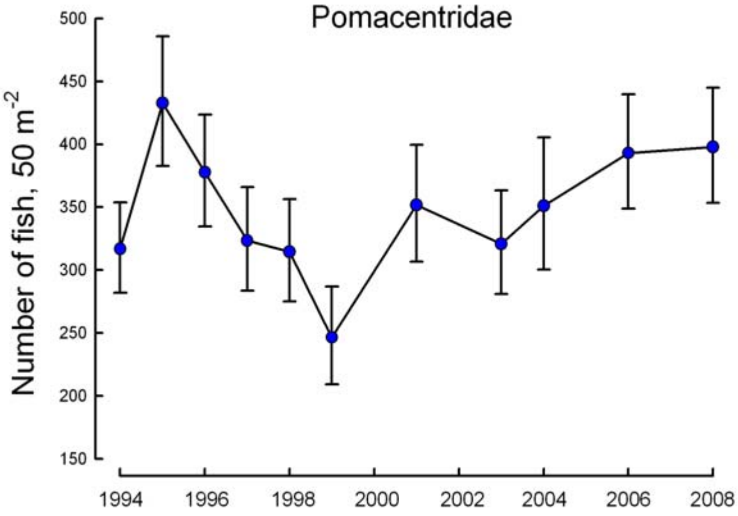
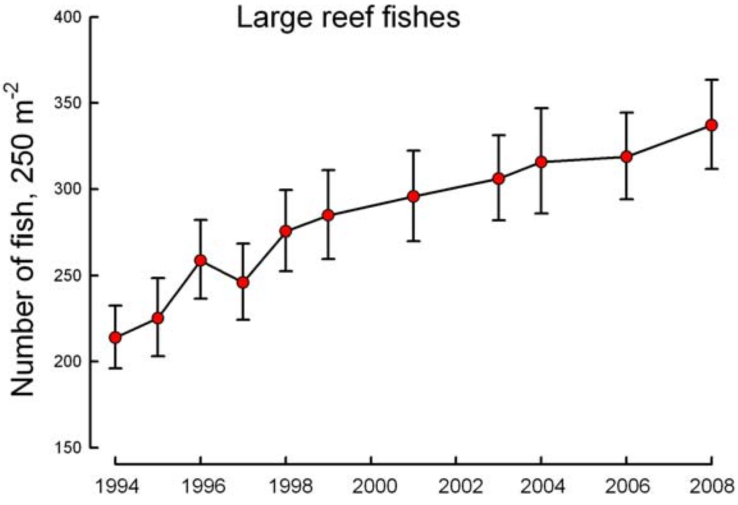


Fig. 15 Mean abundance values of large reef fishes at Scott Reef between 1994 and 2008.



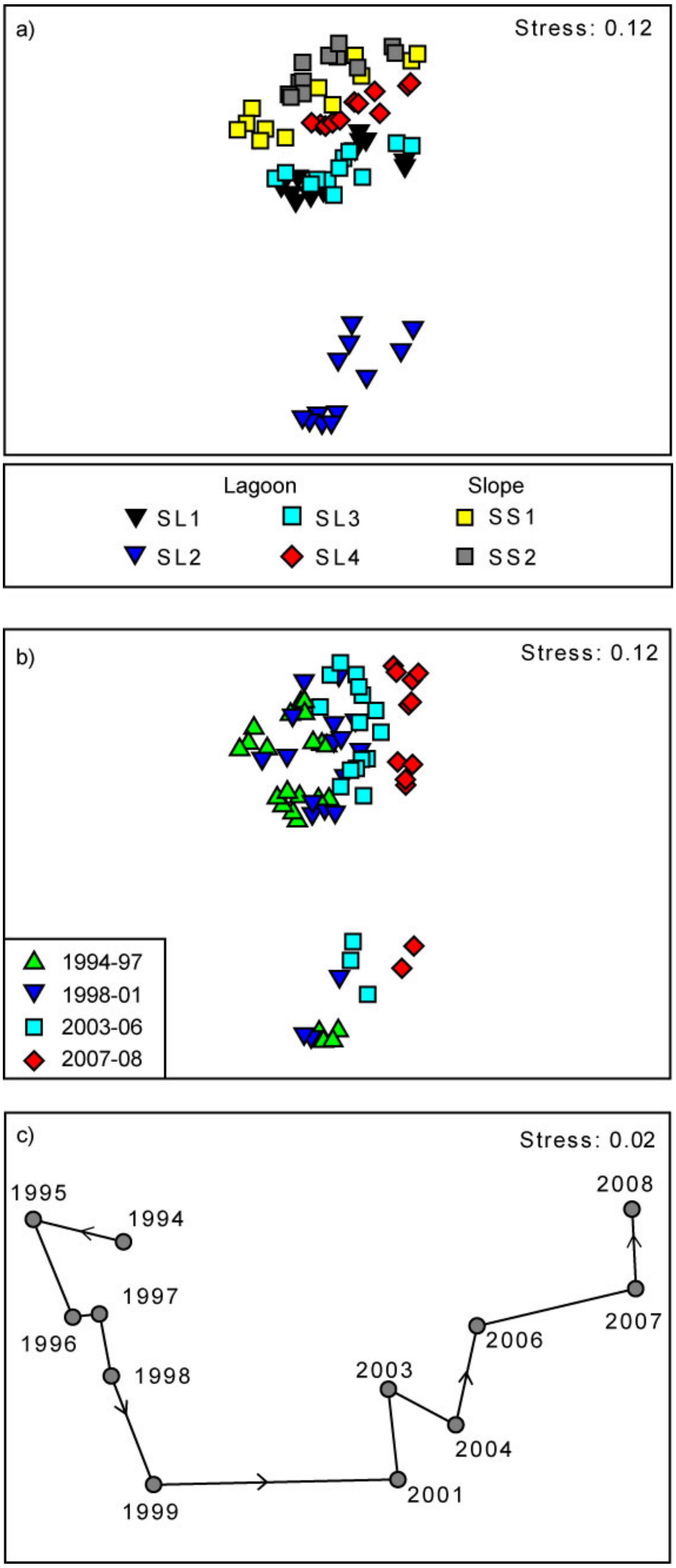


Fig. 16 Non-metric multidimensional scaling (nMDS) ordinations of the species compositions of fish assemblages at six locations at Scott Reef between 1994 and 2008 coded separately for (a) location and (b) year groups and (c) ordination of the species composition in each year averaged across all locations.

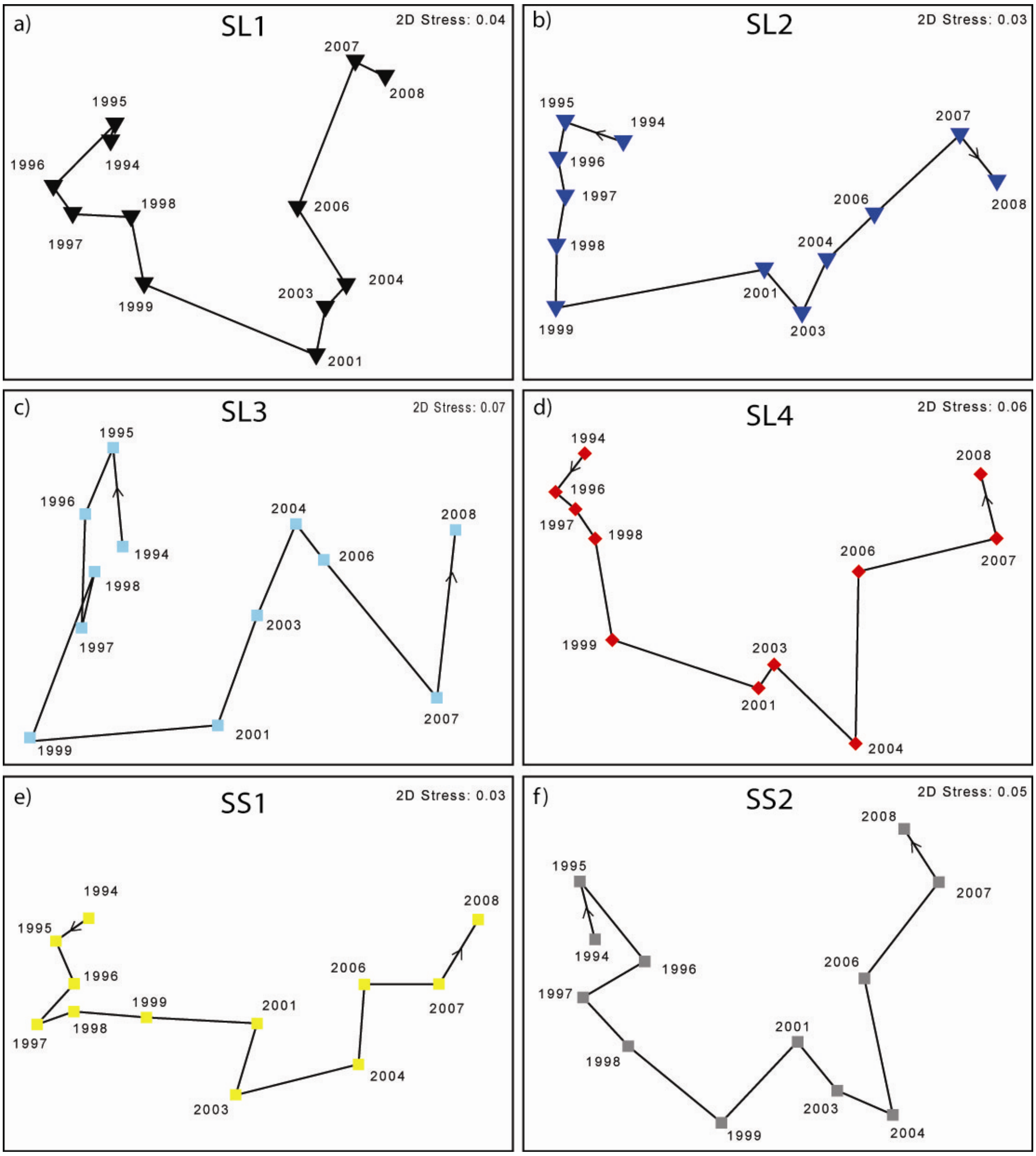


Fig. 17 Non-metric multidimensional scaling (nMDS) ordinations of the species compositions of fish assemblages at each of the six locations at Scott Reef between 1994 and 2008.

Some species of fish display characteristic associations with benthic communities. In general, fish heavily dependent on hard coral for food and or shelter are expected to decline when coral cover declines, and species that utilise algae as their primary food source will increase when the coral cover is replaced by algae. For example the numbers of the coral associated butterflyfish *Chaetodon trifascialis* decreased after the bleaching event in 1998, remained low until 2002, and then increased between 2003 and 2008 following the increase in cover of hard corals (Fig. 18). The damselfish species *Chromis ternatensis* is most common on the outer slope locations and requires live coral for shelter. Its response to the bleaching event was delayed by 12 months, which indicates a gradual reduction in numbers over that period. However, there was an increasing trend in numbers since 2003, largely reflecting the recovery of coral habitat (Fig. 19). In contrast, the numbers of the territorial herbivorous damselfish *Plectroglyphidodon lacrymatus* increased following the bleaching and reached a peak in 2003 before sequentially decreasing to 2008 (Fig. 20). The initial increasing trend may reflect a period when algal cover and food was high following the bleaching, and/or a reduction in competition increased suitable habitat. The latter trend of decreasing abundance may reflect the shift from an algal dominated substrate to one in which hard corals have increased in cover, reducing the space for the farming of the 'algal gardens' that this species defends (Ceccarelli et al. 2001).

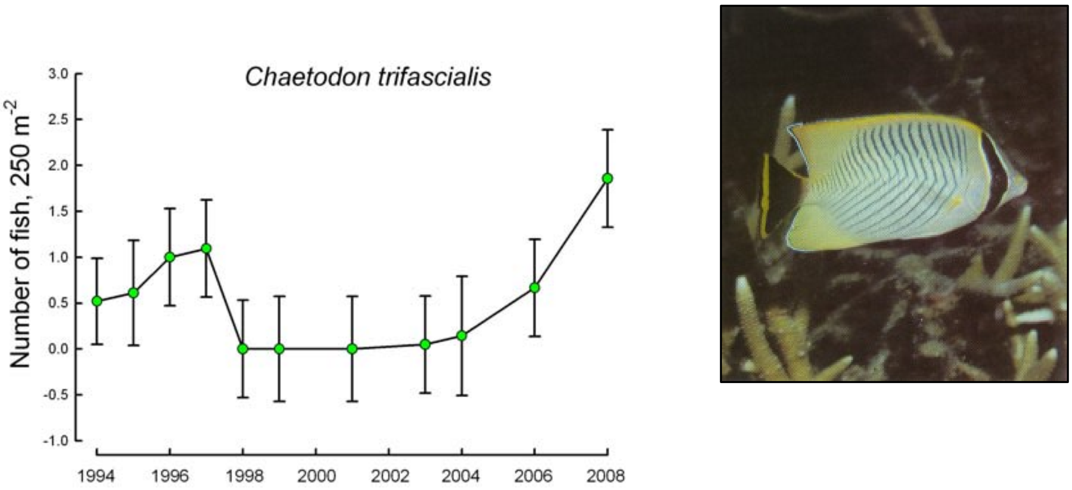


Fig. 18 Mean abundance values of *Chaetodon trifascialis* between 1994 and 2008.

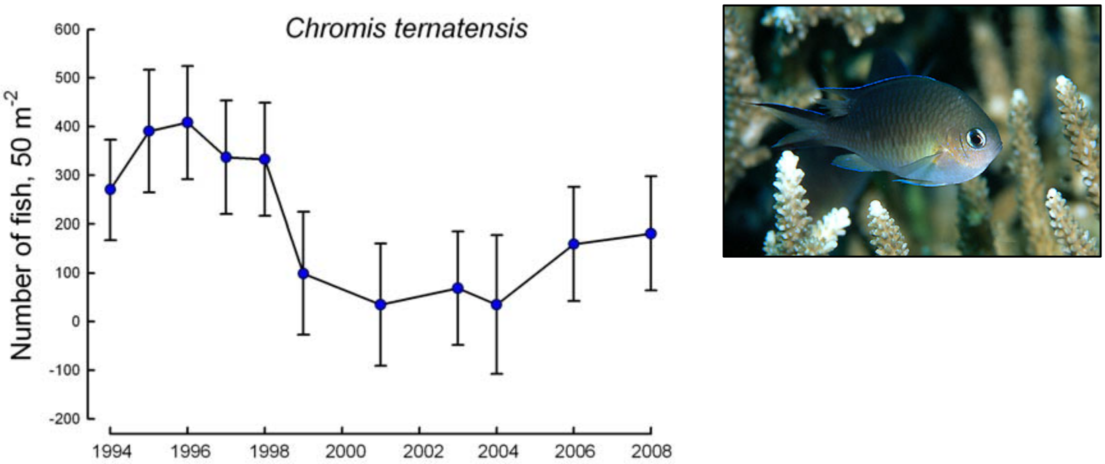


Fig. 19 Mean abundance values of *Chromis ternatensis* between 1994 and 2008.

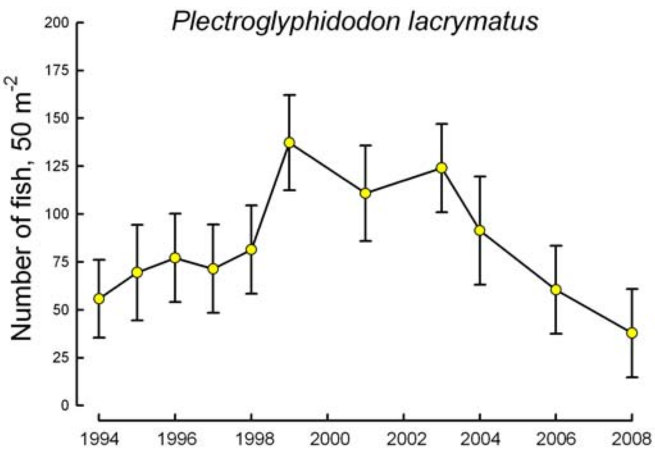


Fig. 20 Mean abundance values of *Plectroglyphidodon lacrymatus* between 1994 and 2008.

3.2 Coral Demography

The rates of survival and growth of Acropora spicefera colonies varied according to their exposure to cyclone disturbance and susceptibility of their different size classes (Fig. 21). Differences in growth and survival of among locations and size classes were consistent over the two year study period, reflecting the impact of Cyclone George in March 2007. Because Cyclone George occurred at the end of one survey period (June 2006 to June 2007), and shortly before the next (June 2007 to May 2008), its impacts were evident over the two years. In general, colonies at locations SL3 and SL4 were the worst impacted by Cyclone George, consistently having the lowest rates of growth and survival, and survival was lowest for the largest size classes. In contrast, colonies at location SL2 were sheltered from the impacts of the cyclone and had high rates of growth and survival for all size classes (Fig. 21).

Colonies at locations SL3 and SL4 had low rates of survival (40 to 65% yr^{-1}) between 2006 and 2008, and comparatively low rates of growth, reflecting their exposure to the impacts of Cyclone George (Fig. 21). In particular, the larger (> 15cm) colonies were most susceptible to the wave energy generated by the cyclone, and had the lowest rates of survival and a high incidence of negative growth following injury and the loss of live tissue (Fig. 21). The longer-term consequences of injury to larger colonies following the cyclone (May 2007) was evident in their low (< 30% yr^{-1}) rates of survival the following year (Fig. 21). In contrast, Location SL1, and particularly SL2, were comparatively sheltered from the impact of Cyclone George, and therefore had higher rates of growth and survival that were similar across the different size classes (Fig. 21). The survival of colonies of all sizes classes over the two year period ranged between 75 and 90% yr^{-1} at SL1, and was > 94% yr^{-1} at SL2; rates of growth ranged between 2.5 and 5.5 cm yr^{-1} at SL1, and between 4.5 and 10.1 cm yr^{-1} at SL2 (Fig. 21).

These initial data on growth and survival of a corymbose species at Scott Reef provide valuable insights into the demography of corals when exposed to 'natural' regimes of disturbance. The annual rates of growth and survival at locations not exposed to cyclone disturbance were high, and similar across size classes. In contrast, the survival of corals at reefs exposed to more localised anthropogenic disturbances (e.g. overfishing, degraded water quality) are more size-specific, with smaller corals having lower rates of survival than larger corals (Hughes 1984). However, anthropogenic stressors are characteristically associated with increased growth of algae and sedimentation, both of which may disproportionately impact smaller corals. In contrast, reefs such as Scott Reef have much lower abundances of algae and sedimentation, with disturbances more commonly in the form of periodic cyclones. The contrasting impact of cyclone disturbance was evident in the reduced rate of growth and survival of the largest colonies, whereas the growth and survival of the smallest size classes remained relatively high (Fig. 21). Thus, from these preliminary data, mean rates of survival for small colonies over several years may prove to be higher than for larger colonies. Data collection over several years is required to confirm these initial patterns of growth and survival, and their responses to different disturbance regimes. In particular, the variation in the demographic traits of different size classes will be quantified with the continued increase in the cover and density of corals, because existing patterns may vary with an increased interaction among individuals (e.g Tanner 1996).

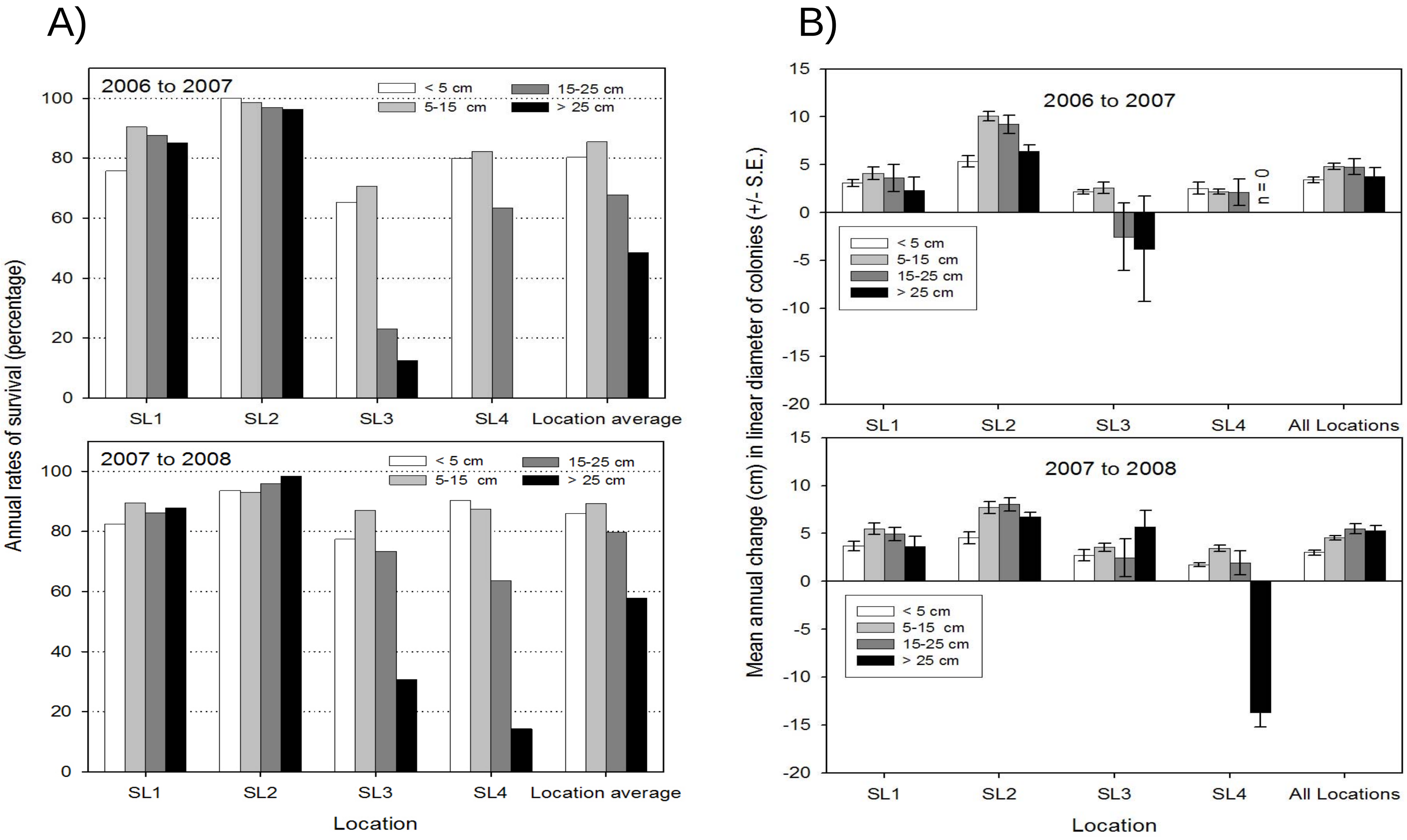


Fig. 21 A) Annual rates of survival and B) growth for size classes (linear diameter) of *Acropora spicifera* at locations across Scott Reef. Rates of growth are the mean annual changes in the linear diameter (cm) of colonies between surveys conducted in May/June each year; mean negative rates of growth reflect decreases in size of colonies and/or the amount of live tissue on colonies following disturbance and injury.

3.3 Genetic Connectivity of Coral and Fish

In April 2008, a total of 580 individuals of each species were collected from 14 sites for *Chromis margeritifer*, and 12 sites for *Cheilodipterus artus*, at Scott Reef and Rowley Shoals (Table. 2). Sample sizes per site ranged from between 30 and 60 individuals for each species at each site, which will provide strong statistical power for detecting genetic structure and differentiation. In addition to *Cheilodipterus artus*, *Cheilodipterus quinquelineatus* also occurs at Scott Reef and Rowley Shoals, and is impossible to distinguish these sister species underwater. Therefore, during the recent field trip, some *C. quinquelineatus* were incidentally collected (Table 2), and these samples may be utilised to compliment the *C. quinquelineatus* data. In addition to the genetic tissue collections, data on sex, reproductive status and size of each fish were also recorded, and whole samples have been frozen for otolith examination. This data will yield invaluable information about early life history characteristics of the fish, such as pelagic larval duration, age and growth.

Table 2 GPS locations and sample sizes of *C. margeritifer* and *C. isostigmus* at Rowley Shoals and Scott Reef.

Site	GPS	*Chromis margaritifer*	*Cheilodipterus artus*	*Cheilodipterus quinquelineatus*
SL1	14º 04.917' S 121º 56.831' E	50	60	-
SL3	14º 04.142' S 121º 46.601' E	41	47	9
SL4	14º 01.459' S 121º 51.720' E	50	31	23
SL6	17º 08.303' S 119º 39.620' E	14	31	20
SS1	14º 04.576' S 121º 58.554' E	49	63	-
SS2	13º 55.305' S 121º 54.864' E	37	50	-
SS3	13º 37.927' S 122º 01.259' E	32	-	-
SS4	13º 41.893' S 122º 02.431' E	35	-	-
RS1_S	17º 03.774' S 119º 38.885' E	52	-	-
RS1_L	17º 04.201' S 119º 38.596' E	-	50	19
RS2_S	17º 08.303' S 119º 39.620' E	44	-	-
RS2_L	17º 08.272' S 119º 39.216' E	-	57	-
RS3_S	17º 15.285' S 119º 21.667' E	53	-	-
RS3_L	17º 17.405' S 119º 22.196' E	-	50	26
RS4_S	17º 23.389' S 119º 22.248' E	38	-	-
RS4_L	17º 18.748' S 119º 22.074' E	-	39	3
RS5_S	17º 30.552' S 118º 57.933' E	47	-	-
RS5_L	17º 32.568' S 118º 57.870' E	-	49	-
RS6_S	17º 39.445'S 118º 55.321' E	44	-	-
RS6_L	17º 35.335'S 118º 58.155' E	-	60	-
Total		586	587	100

A high throughput DNA extraction protocol modified from (Ivanova et al. 2006) has been optimised, which has greatly enhanced the efficiency of the DNA extraction from these samples. DNA has been extracted from over 80% of the individuals collected so far (more than 1000), and quality and quantity of DNA has been ascertained through gel electrophoresis and spectrometry, as well as successful amplification with universal mtDNA primers.

Significant progress has been made in the development of microsatellite markers for the first species *C. margeritifer*. Four microsatellite libraries consisting of different repeat motifs (one trimer; AAC, and three tetramers; CATC, TACA, TAGA) have been constructed, with more than 50% of clones enriched for microsatellites in each library. The next step is to sequence 96 clones from these libraries, and then design and optimise at least ten primer pairs that amplify reliable and polymorphic loci. Finally, multiplex reactions that combine several different loci in the one reaction will be optimised in order to increase the cost and time efficiency of the data acquisition stage. Currently, this development stage is on track for completion by Dec 2008. Once completed, development of microsatellites for the second species, *C. artus*, will commence.

The development of the mtDNA markers has also progressed, with most initial technical difficulties overcome. These technical difficulties were expected, given that these markers have not been used before on this species, and involved optimisation of reagent type and concentration, PCR conditions and quantity of DNA starting material. The first sequences for *C. margeritifer* are currently being analysed; the acquisition of the mtDNA data is likely to be completed for this species by Dec 2008.

3.4 Coral Reproduction and Recruitment

Pre-Spawning Visual Survey

The developmental stage of coral eggs during March 2008 provides further support that autumn is the dominant coral spawning period at Scott Reef. In total, 220 colonies from 48 species of scleractinian corals (16 genera, eight families) were scored at 5 locations across Scott Reef (Table 3), of which 86% of all colonies, and at least 83% of all species were expected to spawn in autumn. In the *Acropora* genus, a total of 195 colonies from 32 species were sampled, of which 84% of colonies and 81% of species were expected to spawn in autumn.

Based on these data and those collected in October 2007 (Gilmour et al. 2007b), all species of *Acropora* participate in the autumn spawning, and no species spawn exclusively in spring, with the possible exception of *A. millepora*. However, there is evidence that populations of at least five species of *Acropora* participate in both autumn and spring spawning events (Table 5), but it is not known whether individual colonies participate in one or both of these events. Of the 25 colonies from 16 species of non-*Acropora* corals sampled (families Faviidae, Merulinidae, Oculinidae, and Pectiniidae), all but one colony were expected to spawn in autumn.

Of the species and colonies predicted to spawn in autumn, the proportion spawning in March versus April was uncertain. Based on previous data, it was initially assumed that colonies with large and pigmented eggs (Score 1) spawned during March, whereas those with weakly pigmented (Score 1/2), or unpigmented (Score 2), eggs spawned in April (Table 3 & 4). However, a rapid visual survey conducted in early April 2008 suggested that many of the colonies expected to spawn after the full moon in April had already spawned; most of these probably had weakly pigmented eggs and were Scored 1/2 during the March survey. Approximately 110 colonies of locally dominant *Acropora* species were visually surveyed for eggs at locations SL3, SL4, and SS1 in April, and with the exception of the brooding corals (*A. brueggemanni, A. palifera*, and *Seriatopora hystrix*) none had visible eggs. The key drivers behind the spawning by corals with weakly pigmented eggs remains to be determined, and is rarely reported in the literature. This early spawning may be linked to oceanographic conditions or comparatively cool water temperature leading up to the spawning in 2008. Environmental variables including sea surface temperatures, solar insolation, lunar cycles, and photo period are known to influence gamete development and release times (van Woesik et al. 2006). The spawning of unpigmented eggs has occasionally been documented, indicating that egg pigmentation is not an entirely reliable proxy for gamete maturity and spawning time.

Table 3 Reproductive state of *Acropora* colonies at Scott Reef prior to the spawning event in March 2008, showing the number of colonies scored at different stages of gametogenesis. Score 1 = pink or red eggs, Score 2 = large white or cream eggs, Score 3 = small white or cream eggs, Score 4 = no visible eggs, Score 1/2 = unresolved egg state (between 1 and 2). For colonies where *in situ* scoring could not be determined, a voucher sample was collected for later analysis. All species that were scored as 1, 2, or 1/2 were inferred to have spawned in the March spawning event based on the absence of eggs in these species in early April. A rapid assessment conducted in early April indicated that many of the colonies with eggs assigned a score of either 1/2 or 2, may have spawned following the full moon in March, and not in April as expected.

Species	Location SL1					Location SL2					Location SL3					Location SL4					Location SS2					Locations All Sites					Total	
	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	Scored	Vouchers (n)
Acropora																																
A. abrolhosensis										1																				1	1	
A. aculeus																																3
A. anthocercis			1															2										3			3	1
A. brueggemanni											2															2					2	9
A. carduus			1			1																				1		1			2	
A. cerealis			6					1		1			1					5					5					18		1	19	3
A. cytherea			3					1		4			2					2					2					10		4	14	4
A. digitifera			1					2					1															4			4	1
A. echinata																																1
A. florida								2		3																		2		3	5	4
A. gemmifera			3					6					6					3					2					20			20	4
A. grandis										1																				1	1	1
A. granulosa						1												1								1		1			2	
A. humilis			1					4					4					3					1					13			13	1
A. hyacinthus			2					1		2			3					3					2					11		2	13	1
A. indonesia								1		1																		1		1	2	3
A. intermedia								1																				1			1	2
A. latistella			2																				1					3			3	5
A. loripes																		1										1			1	
A. microclados			4							1			1															5		1	6	6
A. microphthalma			1					2		1			1										1					5		1	6	6
A. millepora										1																				1	1	2
A. monticulosa															1															1	1	1
A. muricata										3																				3	3	2
A. nasuta			3					3		2			4					5					1					16		2	18	4
A. palifera																1										1					1	11
A. polystoma													3															3			3	2
A. samoensis			2					3																				5			5	
A. spicifera			4					3					1										7					15			15	
A. subglabra								4																				4			4	
A. subulata			1							3													1					2		3	5	2
A. tenuis			3					2		4			3					2					2					12		4	16	3
A. valenciennesi										2																				2	2	1
A. valida													1										2					3			3	3
A. vaughani																																1
Total colonies			38			2		36		3	2		31		1	1		27					27			5		159		31	195	96
Total species																															32	28

Table 4 Reproductive state of non-*Acropora* colonies at Scott Reef prior to the spawning event in March 2008, showing the number of colonies scored at different stages of gametogenesis**.**

Score 1 = pink or red eggs, Score 2 = large white or cream eggs, Score 3 = small white or cream eggs, Score 4 = no visible eggs, Score 1/2 = unresolved egg state (between 1 and 2). For colonies where *in situ* scoring could not be determined, a voucher sample was collected for later analysis. All species that were scored as 1, 2, or 1/2 were inferred to have spawned in the March spawning event based on the absence of eggs in these species in early April. A rapid assessment conducted in early April indicated that many of the colonies with eggs assigned a score of either 1/2 or 2, may have spawned following the full moon in March, and not in April as expected.

Species	Location SL1					Location SL2					Location SL3					Location SL4					Location SS2					Locations All Sites					Total	
	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	Score	Vouchers (n)
Acroporidae																																
Astreopora gracilis																																2
Astreopora myriophthalma																																3
Agariciidae																																
Pachyseris speciosa																																1
Pachyseris rugosa																																2
Pavona clavus																																1
Pavona venosa																																1
Faviidae																																
Echinopora lamellosa																																3
Echinopora mammiformis																																2
Favia danae												1															1				1	1
Favia matthai												1					1										2				2	3
Favia pallida												1															1				1	1
Favia stelligera												1					1										2				2	5
Favia truncatus																																2
Favites abdita												2															2				2	3
Favites russelli																																1
Goniastrea aspera																	1										1				1	2
Goniastrea edwardsi										1							3										3			1	4	7
Goniastrea favulus												1					1										2				2	2
Goniastrea pectinata												1															1				1	3
Goniastrea retiformis												1															1				1	2
Leptastrea aequalis																																3
Montastrea curta																																2
Platygyra daedala												1															1				1	1
Platygyra pini																																
Platygyra ryukuensis													1															1			1	3
Merulinidae																																
Merulina ampliata												1															1				1	1
Oculinidae																																
Galaxea astreata												1															1				1	1
Galaxea fascicularis												1															1				1	2
Pectinidae																																
Mycedium elephantotus																																1
Mycedium mankaoi						1		2																		1		2			3	1
Pocilloporidae																																
Seriatopora hystrix																																17
Siderastreidae																																
Psammocora digitata																																1
Total Colonies						1		2		1		13	1				7									1	2(	3		1	25	82
Total Species																															16	32

Table 5 Participation by selected *Acropora* species in multi-specific spawning events in autumn (March / April) and/or spring (October / November).

Species	autumn	spring
A. spicifera	x	
A. millepora		x
A. digitifera	x	
A. tenuis	x	x
A. florida	x	x
A. valida	x	
A. gemmifera	x	x
A. humilis	x	
A. hyacinthus	x	x
A. cytherea	x	x

Pre-spawning sampling surveys

Samples from 121 colonies of *Acropora spicifera,* 96 colonies of *Acropora spp.* (28 species) and 82 colonies of non-*Acropora* species (32 species from the families Acroporidae, Agariciidae, Faviidae, Merulinidae, Oculinidae, Pectiniidae, Pocilloporidae, Siderastreidae) were collected for laboratory analyses of fecundity and oocyte size. Laboratory work and data analyses are ongoing, however samples that have been analysed for fecundity and oocyte size are summarised below (Table 6).

Larval supply and recruitment of corals

The rates of larval supply and recruitment at Scott Reef have continued to increase since the bleaching, with a particularly large increase in 2008 (Fig. 22). The mean rates (± S.E.) of recruitment at Scott Reef have increased from < 0.3 (± 0.2) recruits plate^{-1} yr^{-1} one year after the bleaching (1999), to 2.3 (± 1.5) in 2003, and 70.4 (± 57) in 2008. On average, the rates of recruitment ten years after the bleaching in 2008 had exceeded the mean (± S.E.) pre-bleaching rate of 53 recruit's plate^{-1} yr^{-1} in 2007. The rapid increases in recruitment in recent years (>2004), compared with those shortly after (< 2004) the bleaching, probably reflect the maturation and rapid increases in colony size from approximately 5 years after the bleaching. Thus, after 2003, there was a corresponding increase in the number of colonies of adult size (Smith et al. 2006), and rapid increases in the percentage cover of hard corals. The largest coral colonies are known to make a disproportionately high contribution to reproductive output, because the numbers of polyps in a colony increases exponentially with size (Hall and Hughes 1996).

Although the mean rate of recruitment in 2008 had surpassed that prior to the bleaching, this was not the case at all locations and there was considerable spatial variation in recruitment across Scott Reef. By far the highest mean (± S.E.) rates of recruitment in 2008 were 354 (± 52) recruits plate^{-1} yr^{-1} at location SL1, which was more than four times that prior to the bleaching or that at any other location at Scott Reef. Additionally, location SL1 consistently had the highest recruitment of all locations before and after the bleaching event. By comparison, there were much smaller increases in recruitment at all other locations after 2003, and by 2008 the mean rates of recruitment (± S.E.) at locations SL2, SL3, SL4 and SS1 ranged between 5 and 35 (± <5) recruits plate^{-1} yr^{-1} . The rates of recruitment in 2008 were similar or greater than those prior to the bleaching at all locations, with the exception of location SS2; at SS2 the mean (± S.E.) rate of recruitment in 2008 was 1.6 (± 0.4) recruits plate^{-1} yr^{-1}, which was less than 20% of that prior to the bleaching.

Table 6. Polyp fecundity, fecundity per cm2, and oocyte geometric mean diameter of coral samples, Scott Reef 2008.

Species	Polyp Fecundity Mean	Polyp Fecundity SE	Maximal Mean	Maximal SE	Medial Mean	Medial SE	Geometric Mean	Geometric SE	Colonies N	Eggs N
Acropora aculeus	4.86	0.16	137.15	1.77	106.59	1.82	120.30	1.70	3	356
Acropora anthocercis	5.55	0.25	170.52	6.17	115.67	4.13	139.75	4.89	1	147
Acropora cerealis									1	0
Acropora cytherea	5.36	0.16	183.58	2.24	135.85	1.46	156.95	1.58	3	398
Acropora digitifera	4.28	0.22	579.35	12.79	467.16	8.20	514.05	6.83	1	110
Acropora echinata									1	0
Acropora gemmifera	4.93	0.17	139.93	1.68	108.75	1.17	122.76	1.23	3	342
Acropora grandis									1	0
Acropora hyacinthus	4.66	0.11	164.37	2.41	125.27	1.87	142.78	2.04	7	590
Acropora indonesia	6.73	0.22	543.47	11.35	372.09	6.43	444.16	7.47	2	348
Acropora latistella	5.01	0.14	376.99	10.64	247.88	6.85	302.83	8.14	4	496
Acropora microclados	5.59	0.19	198.80	3.93	149.40	2.85	171.44	3.20	4	392
Acropora microphthalma	1.00	0.00	466.93	32.85	392.70	34.84	427.95	33.23	1	4
Acropora millepora	5.56	0.20	155.88	2.17	122.14	1.27	136.89	1.33	2	280
Acropora muricata	4.68	0.29	123.47	2.45	64.94	1.51	89.09	1.74	2	103
Acropora nasuta									2	0
Acropora polystoma	5.59	0.26	217.51	5.26	142.20	2.37	174.45	3.12	1	148
Acropora spicifera	5.01	0.09	627.74	4.34	443.58	2.88	521.41	2.48	9	1081
Acropora subulata	6.88	0.22	179.08	2.22	138.33	1.70	156.76	1.78	2	356
Acropora tenuis	5.96	0.22	125.33	1.57	102.58	1.36	112.63	1.24	2	290
Acropora valenciennesi									1	0
Acropora valida	2.43	0.17	1149.88	35.98	370.56	15.57	632.33	13.43	1	53
Goniastrea pectinata									1	0
Seriatopora hystrix									1	0

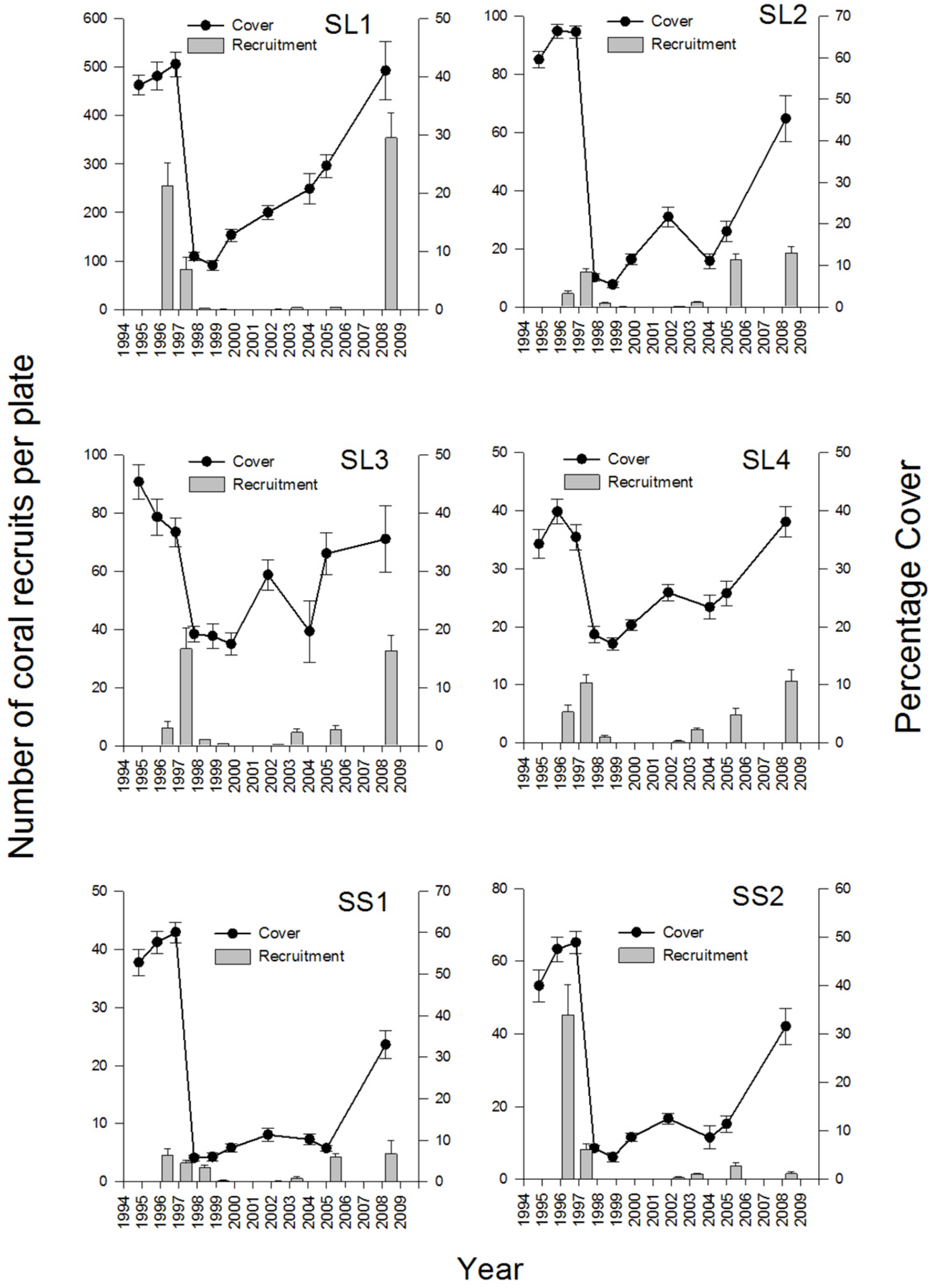


Fig. 22 Changes in percentage cover and recruitment of hard corals at locations across Scott Reef. The mass-bleaching occurred in 1998, Cyclone Fay in 2004 and Cyclone George in 2007.

Spatial variation in recruitment among the locations at Scott Reef is driven by the local abundance of adult colonies, the distances of larval dispersal, and the oceanographic conditions during the dispersal period. Rates of recruitment at each location are influenced by the abundance and size of adult colonies at those locations (< 10 kilometres). Additionally, there is increasing evidence that coral larvae at Scott Reef may settle out of the water column within a week of spawning and may routinely disperse over distances of approximately 10 kilometres (Underwood et al. 2008; Gilmour et al. in press; Underwood in revision). However, oceanographic conditions during this dispersal period certainly play an important role in determining the degree of connectivity among locations and reefs across the Scott Reef system. In particular, oceanographic conditions clearly disperse larvae from other lagoonal communities and supply the highest rates of recruitment to location SL1 at the inner west hook (Steinberg et al. 2006).

3.5 Physical Data

Temperature

Temperature loggers deployed previously at three locations in March 2007 were retrieved in March the following year (2008). Mean daily water temperatures ranged from a low of 25.7˚C at SL3 on 9 August 2007 to maxima of 31.1 ˚C at SL1 in February 2008 (Fig. 23). Seasonal trends were similar among locations. There were bi-modal peaks in summer 2007/2008 temperatures (*ca* 30˚C) at each location with an initial peak on 16 December 2007 and a secondary peak on 4 February 2008, separated by a period of lower water temperature (*ca* 28.5˚C) in January 2008 (Fig. 23).

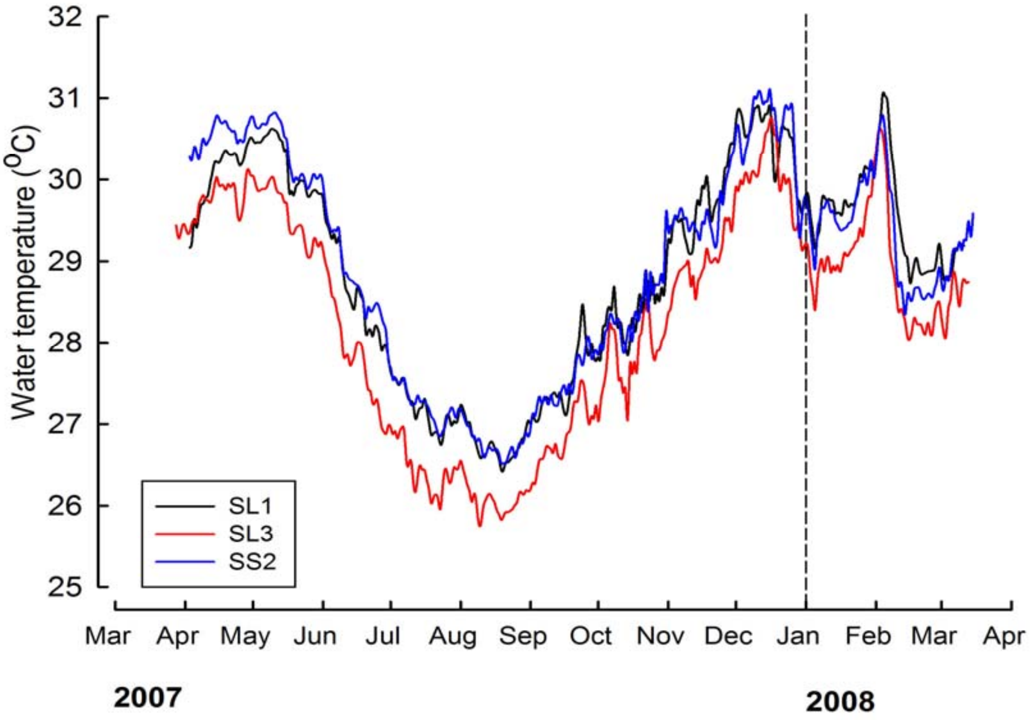


Fig. 23 Mean daily water temperatures at three shallow (9m) locations at Scott Reef between April 2007 and April 2008.

Water temperatures in shallow (*ca* 9 m) waters at Scott Reef followed a seasonal cycle of a high in May 2007 (*ca* 30.0˚C) and a winter low in August 2007 (*ca* 26.5˚C) followed by a sequential increase through to bimodal summer peaks of *ca* 30.5˚C in December 2007 and February 2008. Water temperature did not exceed the estimated bleaching threshold temperature of approximately 31˚C for more than two days. There was minimal variation in mean daily water temperature between locations SL1 and SS2, however temperatures were consistently 0.5˚C lower at SL3. The cooler temperatures at SL3 are a consequence of the regular tidal incursions of cooler oceanic water between West Hook and Sandy Islet (Steinberg et al. 2003; Bird et al. 2004).

Sedimentation

Mean sedimentation rates at 3 locations at Scott Reef between February and April 2008 ranged from a low of 0.45 mg cm^{-2} d^{-1} at SL2 to a high of 1.25 mg cm^{-2} d^{-1} at SL1 (Fig. 24). Except for SL1 and SL4 all locations had sedimentation rates < 1.0 mg cm^{-2} d^{-1}.

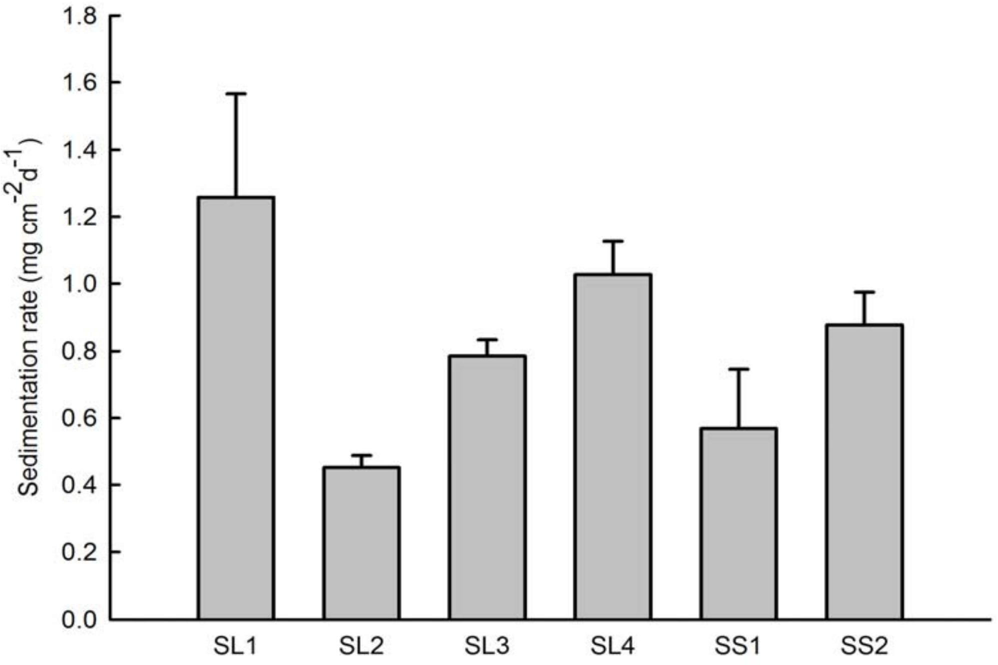


Fig. 24 Mean sedimentation rate (mg cm^{-2} d^{-1} ± 1 S.E.) at six locations at Scott Reef between late February and late May 2008.

The mean sediment deposition rates recorded at Scott Reef between February and May 2008 are at the lower extent of the range (< 1 to 10 mg cm^{2} d^{-1}) expected at reefs not subjected to stresses from human activities (Rogers 1990). These rates are consistent with mean deposition rates at clear water sites in north-western Australia (Simpson 1988) and New Guinea (Kojis and Quinn 1984) where mean deposition rates during calm periods were 1.4 mg cm^{2} d^{-1} and 1.0 mg cm^{2} d^{-1}, respectively. The mean deposition rates at Scott Reef are also consistent with those recorded at reef locations in Jamaica and the U.S. Virgin Islands where values ranged from 0.1-1.6 mg cm^{2} d^{-1} (Dodge et al. 1974).

3.6 Deep Water Communities

In February 2008, 315 coral samples were collected from the deep lagoon habitats of Scott Reef for taxonomy, genetic and reproductive analyses. Preliminary taxonomic analyses of the deep water specimens have recorded a total of 51 scleractinian coral species from 27 genera and 11 families. These initial records of deep water taxonomic diversity at Scott Reef are likely to be significantly below true species diversity at depth due to the limited sampling regime and the inherent bias with the capture of coral species using the benthic grab apparatus. While the benthic grab has successfully captured many of the foliaceous and arborescent coral species, deep water video imagery has shown that many colonies of encrusting and massive species (e.g. Faviidae and Poritidae) are present at depth but have not been collected in grabs. It is therefore expected that additional or modified sampling regimes will result in an upward revision of species recorded from the deep lagoon habitats at Scott Reef.

Of the taxonomic records made in 2008, eight species are new records for Scott Reef, of which 5 are new records for Western Australia and two are new records Australia-wide. Eleven species recorded from Scott Reef have been found only in the deep water habitats. Data from shallow water taxonomic surveys by Veron (1986), Done (1994), Wolstenholme (2004, Unpublished data), and McKinney (2007 unpublished data; 2008 unpublished data) were also rationalised to a common taxonomy and compiled to produce an aggregate species list of deep and shallow water corals at Scott Reef.

In addition to the deep water species records, 295 scleractinian coral species from 58 genera and 14 families have been recorded from the shallow water habitats at Scott Reef. In total, 306 coral species from 60 genera and 14 families have been recorded from both the deep and shallow habitats. Community composition in the deep water lagoon is markedly different to the shallow water habitats; shallow water coral communities are comprised of typical reef front, lagoon, and reef flat assemblages, while the deep water communities are dominated by extensive areas of foliaceous Agariciidae, Pectiniidae, Poritidae, and *Montipora* species, combined with fragile arborescent and plate-like *Acropora* species.

Scott Reef coral taxa are predominately widespread Indo-Pacific species that present clear affinities with the coral assemblages of Ashmore Reef and the Indonesian provinces to the north. In future analyses, non-parametric multi-dimensional scaling will be utilised to examine the relationship between the deep and shallow water communities at Scott Reef, and place these communities within the regional context of neighbouring oceanic and coastal reef systems.

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Appendices

Appendix 1. Number of fish species recorded for each family at the Rowley Shoals and Scott Reef and Ashmore Reef systems (after Allen 1993; Hutchins et al. 1995)

Family	Common Name	Rowley Shoals	Scott/ Seringapatam R	Ashmore Reef/ Cartier I.
Acanthuridae	Surgeonfishes	21	33	21
Antennariidae	Anglerfishes or Frogfishes	4	0	3
Apogonidae	Cardinalfishes	26	40	38
Atherinidae	Hardyheads or Silversides	3	2	0
Aulostomidae	Trumpetfishes	1	1	1
Balistidae	Triggerfishes	12	14	11
Belonidae	Longtoms or Needlefins	1	4	1
Blenniidae	Blennies	22	17	15
Bothidae	Lefteye flounders	3	1	2
Brotulidae	Eel-pouts	1	0	0
Bythitidae	Cuskeels	3	0	3
Caesionidae	Fusiliers	3	9	6
Callionymidae	Dragonets	3	2	2
Caracanthidae	Crouchers or Orbicular Velvetfishes	1	1	1
Carangidae	Trevallies	16	15	6
Carapidae	Pearlfishes	0	0	1
Carcharhinidae	Whaler sharks or Requiem sharks	5	5	2
Chaetodontidae	Butterflyfishes	27	37	24
Cirrhitidae	Hawkfishes	2	6	4
Clupeidae	Herrings and Sardines	0	2	1
Congridae	Conger Eels	0	0	5
Creediidae	Sand Burrowers	1	0	0
Dasyatididae	Stingrays	1	2	2
Diodontidae	Porcupinefishes	2	3	1
Echeneididae	Remoras	2	1	0
Elotridae	Gudgeons or Sleepers	3	0	2
Ephippidae	Batfishes	3	6	2
Exocoetidae	Flyingfishes	1	2	0
Fistulariidae	Flutemouths	2	1	1
Gerreidae	Mojarras	1	0	1
Ginglymostomatidae	Nurse Sharks	1	1	0
Gobiesocidae	Clingfishes	1	1	2
Gobiidae	Gobies	50	65	67
Grammistidae	Soapfishes	1	2	2
Haemulidae	Sweetlips	2	5	3
Hemiramphidae	Garfishes or Halfbeaks	0	1	2
Hemiscylliidae	Bamboo Sharks	0	1	1
Holocentridae	Squirrel fishes and Soldier fishes	18	19	14
Istiophoridae	Billfishes	1	2	1
Kraemeridae	Sanddarts	0	0	1
Kyphosidae	Drummers or Sea Chubs	4	6	2
Labridae	Wrasses	69	79	54
Lethrinidae	Emperors	14	21	6
Lutjanidae	Snappers	12	23	12
Malacanthidae	Sand Tilefishes	4	3	2
Microdesmidae	Worm fishes and Dartfishes	4	7	5

Family	Common Name	Rowley Shoals	Scott/ Seringapatam R	Ashmore Reef/ Cartier I.
Mobulidae	Manta or Devil Rays	1	3	1
Monacanthidae	Leatherjackets	15	8	6
Moringuidae	Worm Eels	2	1	2
Mugilidae	Mullets	0	0	1
Mugiloididae	Sand Perches and Weavers	2	3	4
Mullidae	Goatfishes	6	11	9
Muraenidae	Moreys	14	18	19
Mylobatidae	Eagle rays	1	3	1
Nemipteridae	Coral Breams	3	6	7
Nomeidae	Driftfishes	1	0	0
Notograptidae	Eel Blenny	0	0	1
Ophichthidae	Snake Eels	4	5	8
Orectolobidae	Wobbygongs	0	0	1
Ostraciidae	Boxfishes	3	2	1
Pempheridae	Sweepers	2	2	2
Pinguipedidae	Grubfishes	0	1	0
Platycephalidae	Flatheads	2	2	2
Plesiopidae	Longfins	3	1	3
Pleuronectidae	Righteye Flounders	1	0	1
Plotosidae	Eeltail Catfishes	1	1	0
Pomacanthidae	Angelfishes	11	14	11
Pomacentridae	Damselfishes	49	76	66
Priacanthidae	Bigeyes	1	1	1
Pseudochromidae	Dottybacks and Eel Blennies	7	10	10
Pseudogrammatidae	Basslet	2	1	1
Scaridae	Parrotfishes	24	31	13
Scombridae	Tunas and Mackerels	6	7	1
Scorpaenidae	Scorpionfishes	6	12	15
Serranidae	Rock cods or Groupers	34	41	19
Siganidae	Rabbitfishes	11	11	5
Soleidae	Soles	2	0	3
Solenostomidae	Ghost pipefishes	1	0	0
Sphyraenidae	Barracudas	3	2	1
Stegastomatidae	Leopard Sharks	0	0	1
Syngnathidae	Pipefishes	10	8	3
Synodontidae	Lizardfishes	3	6	5
Tetraodontidae	Puffers	4	9	6
Tripterygiidae	Triplefins	4	4	7
Xenocongridae	False Moreys	1	2	0
Zanclidae	Moorish Idol	1	2	1
Number of Families		75	69	75
Number species		569	721	568

Appendix 2. Shallow (<30m) and deep water (30-70m) corals recorded at Scott Reef, 1993-2008.

Species	Shallow	Deep	Combined	New Records
Acroporidae				
Acropora abrolhosensis	x		x	
Acropora abrotanoides	x		x	
Acropora aculeus	x		x	
Acropora acuminata	x		x	
Acropora anthocercis	x		x	
Acropora aspera	x		x	
Acropora austera	x		x	
Acropora cf batunai		x	x	Requires confirmation. Potential new record for Australia
Acropora brueggemanni	x		x	
Acropora carduus	x		x	
Acropora caroliniana	x		x	
Acropora cerealis	x		x	
Acropora clathrata	x		x	
Acropora cytherea	x		x	
Acropora cf desalwyii	x		x	Requires confirmation. Potential new record for Australia
Acropora digitifera	x		x	
Acropora divaricata	x		x	
Acropora donei	x		x	
Acropora echinata	x		x	
Acropora elegans		x	x	Requires confirmation. Potential new record for Australia
Acropora elseyi	x		x	
Acropora exquisita	x		x	
Acropora florida	x		x	
Acropora gemmifera	x		x	
Acropora glauca	x		x	
Acropora grandis	x		x	
Acropora granulosa	x		x	
Acropora horrida	x		x	
Acropora humilis	x		x	
Acropora hyacinthus	x		x	
Acropora indonesia	x		x	
Acropora intermedia	x		x	
Acropora cf jacquelinae		x	x	Requires confirmation. Potential new record for Australia
Acropora kimbeensis	x		x	
Acropora kirstyi	x		x	
Acropora latistella	x		x	
Acropora listeri	x		x	
Acropora loisetteae	x		x	
Acropora longicyathus	x		x	
Acropora loripes	x		x	
Acropora lutkeni	x		x	
Acropora microclados	x		x	

Species	Shallow	Deep	Combined	New Records
Acropora microphthalma	x		x	
Acropora millepora	x		x	
Acropora monticulosa	x		x	
Acropora muricata	x		x	
Acropora nana	x		x	
Acropora nasuta	x		x	
Acropora palifera	x		x	
Acropora paniculata	x		x	
Acropora pichoni		x	x	
Acropora polystoma	x		x	
Acropora pulchra	x		x	
Acropora robusta	x		x	
Acropora samoensis	x		x	
Acropora secale	x		x	
Acropora selago	x		x	
Acropora spicifera	x		x	
Acropora striata	x		x	
Acropora subglabra	x		x	
Acropora subulata	x		x	
Acropora cf tenella		x	x	Requires confirmation. Potential new record for Australia
Acropora tenuis	x		x	
Acropora valenciennesi	x		x	
Acropora valida	x		x	
Acropora vaughani	x		x	
Acropora yongei	x		x	
Anacropora forbesi		x	x	Requires confirmation
Anacropora puertogalerae	x		x	
Astreopora cucullata	x		x	
Astreopora expansa	x	x	x	
Astreopora gracilis	x		x	
Astreopora incrustans	x		x	
Astreopora listeri	x		x	
Astreopora myriophthalma	x		x	
Astreopora ocellata	x		x	
Montipora aequituberculata	x	x	x	
Montipora angulata	x		x	
Montipora caliculata	x		x	
Montipora crassituberculata	x	x	x	
Montipora danae	x		x	
Montipora digitata	x		x	New Record for Scott Reef
Montipora efflorescens	x		x	
Montipora floweri	x		x	
Montipora foliosa	x		x	
Montipora foveolata	x		x	
Montipora grisea	x		x	
Montipora hispida	x		x	
Montipora hoffmeisteri	x		x	
Montipora incrassata	x		x	

Species	**Shallow**	**Deep**	**Combined**	**New Records**
Montipora informis	x		x	
Montipora millepora	x		x	
Montipora mollis	x		x	
Montipora monasteriata	x		x	
Montipora nodosa	x		x	
Montipora peltiformis	x		x	
Montipora spumosa	x		x	
Montipora tuberculosa	x		x	
Montipora turgescens	x		x	
Montipora turtlensis	x		x	
Montipora undata	x		x	
Montipora venosa	x		x	
Montipora verrucosa	x		x	
Agariciidae				
Coeloseris mayeri	x		x	
Gardineroseris planulata	x		x	
Leptoseris explanata	x	x	x	
Leptoseris foliosa	x	x	x	
Leptoseris gardineri		x	x	New Record for WA
Leptoseris hawaiiensis	x		x	
Leptoseris incrustans	x		x	
Leptoseris mycetoseroides	x	x	x	
Leptoseris papyracea	x	x	x	
Leptoseris scabra	x	x	x	
Leptoseris solida	x		x	New Record for WA
Leptoseris striata		x	x	
Leptoseris yabei	x	x	x	
Pachyseris rugosa	x		x	
Pachyseris speciosa	x	x	x	
Pavona bipartita	x		x	
Pavona cactus	x	x	x	
Pavona clavus	x		x	
Pavona decussata	x		x	
Pavona duerdeni	x		x	
Pavona explanulata	x		x	
Pavona frondifera	x		x	New Record for WA
Pavona maldivensis	x		x	
Pavona varians	x	x	x	
Pavona venosa	x		x	
Astrocoeniidae				
Stylocoeniella armata	x		x	
Stylocoeniella guentheri	x		x	
Dendrophylliidae				
Turbinaria frondens	x		x	
Turbinaria mesenterina	x		x	
Turbinaria peltata	x		x	
Turbinaria reniformis	x		x	
Turbinaria stellulata	x		x	

Species	Shallow	Deep	Combined	New Records
Euphylliidae				
Euphyllia ancora	x		x	
Euphyllia cristata	x	x	x	
Euphyllia glabrescens	x		x	
Physogyra lichtensteini	x		x	
Plerogyra sinuosa	x		x	
Faviidae				
Caulastrea furcata	x	x	x	
Caulastrea tumida	x		x	
Cyphastrea agassizi	x		x	
Cyphastrea chalcidicum	x	x	x	
Cyphastrea microphthalma	x	x	x	
Cyphastrea serailia	x	x	x	
Diploastrea heliopora	x		x	
Echinopora ashmorensis	x		x	
Echinopora gemmacea	x		x	
Echinopora hirsutissima	x		x	
Echinopora horrida	x		x	
Echinopora lamellosa	x	x	x	
Echinopora mammiformis	x		x	
Favia danae	x		x	
Favia favus	x		x	
Favia helianthoides	x		x	
Favia laxa	x		x	
Favia lizardensis	x		x	
Favia matthaii	x		x	
Favia maxima	x		x	
Favia pallida	x		x	
Favia rotumana	x		x	
Favia rotundata	x		x	
Favia speciosa	x		x	
Favia stelligera	x		x	
Favia truncatus	x		x	
Favites abdita	x		x	
Favites chinensis	x		x	
Favites complanata	x		x	
Favites flexuosa	x		x	
Favites halicora	x		x	
Favites pentagona	x		x	
Favites russelli	x		x	
Favites stylifera	x		x	
Goniastrea aspera	x		x	
Goniastrea australensis	x		x	
Goniastrea edwardsi	x		x	
Goniastrea favulus	x		x	
Goniastrea palauensis	x		x	
Goniastrea pectinata	x		x	
Goniastrea retiformis	x		x	

Species	Shallow	Deep	Combined	New Records
Leptastrea aequalis	x		x	
Leptastrea inaequalis	x		x	
Leptastrea pruinosa	x		x	
Leptastrea purpurea	x		x	
Leptastrea transversa	x		x	
Leptoria phrygia	x		x	
Montastrea annuligera	x		x	
Montastrea curta	x		x	
Montastrea magnistellata	x		x	
Montastrea valenciennesi	x		x	
Oulophyllia bennettae	x		x	
Oulophyllia crispa	x		x	
Oulophyllia levis	x		x	
Platygyra daedalea	x		x	
Platygyra lamellina	x		x	
Platygyra pini	x		x	
Platygyra ryukyuensis	x		x	
Platygyra sinensis	x		x	
Platygyra verweyi	x		x	
Plesiastrea versipora	x		x	
Fungiidae				
Ctenactis crassa	x	x	x	
Ctenactis echinata	x	x	x	
Ctenactis albitentaculata	x		x	New record for WA
Fungia (Cycloseris) costulata	x		x	
Fungia (Cycloseris) vaughani	x		x	
Cantharellus noumeae	x		x	
Fungia concinna	x	x	x	
Fungia fungites	x		x	
Fungia granulosa	x		x	
Fungia horrida	x	x	x	
Fungia moluccensis	x		x	New record for WA
Fungia paumotensis	x	x	x	
Fungia repanda	x	x	x	
Fungia scutaria	x		x	
Fungia (Danafungia) scruposa	x		x	
Halomitra pileus		x	x	New record for WA
Heliofungia actiniformis	x		x	
Herpolitha limax	x	x	x	
Herpolitha weberi	x	x	x	
Lithophyllon mokai	x		x	
Lithophyllon undulatum	x		x	
Podabacia crustacea	x		x	
Podabacia motuporensis	x		x	New record for WA
Polyphyllia talpina	x		x	
Sandalolitha robusta	x	x	x	
Sandalolitha dentata		x	x	New record for Australia
Zoopilus echinatus		x	x	New record for Australia

Species	**Shallow**	**Deep**	**Combined**	**New Records**
Merulinidae				
Hydnophora exesa	x	x	x	
Hydnophora microconos	x		x	
Hydnophora pilosa	x		x	
Hydnophora rigida	x	x	x	
Merulina ampliata	x		x	
Merulina scabricula	x		x	
Scapophyllia cylindrica	x		x	
Mussidae				
Acanthastrea brevis	x		x	
Acanthastrea echinata	x		x	
Australomussa rowleyensis	x	x	x	
Lobophyllia hataii	x		x	
Lobophyllia hemprichii	x	x	x	
Symphyllia agaricia	x		x	
Symphyllia radians	x		x	
Symphyllia recta	x		x	
Symphyllia valenciennesii	x		x	
Oculinidae				
Galaxea astreata	x		x	
Galaxea fascicularis	x		x	
Galaxea horrescens	x		x	
Pectiniidae				
Echinophyllia aspera	x	x	x	
Echinophyllia echinata	x	x	x	
Echinophyllia echinoporoides	x		x	
Echinophyllia orpheensis	x		x	
Mycedium elephantotus	x	x	x	
Mycedium mancaoi	x		x	
Mycedium robokaki	x		x	
Oxypora glabra	x		x	
Oxypora lacera	x	x	x	
Pectinia alcicornis	x		x	
Pectinia lactuca	x		x	
Pectinia paeonia	x		x	
Pectinia teres	x		x	
Pocilloporidae				
Pocillopora damicornis	x		x	
Pocillopora danae	x		x	
Pocillopora eydouxi	x		x	
Pocillopora meandrina	x		x	
Pocillopora verrucosa	x		x	
Pocillopora woodjonesi	x		x	
Seriatopora hystrix	x	x	x	
Stylophora mordax	x		x	
Stylophora pistillata	x	x	x	
Poritidae				
Alveopora allingi	x		x	

Species	Shallow	Deep	Combined	New Records
Alveopora catalai	x		x	
Alveopora fenestrata	x		x	
Alveopora spongiosa	x		x	
Alveopora tizardi	x		x	
Alveopora verrilliana	x		x	
Goniopora burgosi	x		x	
Goniopora columna	x		x	
Goniopora djiboutiensis	x		x	
Goniopora lobata	x		x	
Goniopora minor	x		x	
Goniopora palmensis	x		x	
Goniopora pendulus	x		x	
Goniopora stutchburyi	x		x	
Goniopora tenuidens	x		x	
Porites annae	x		x	
Porites cylindrica	x		x	
Porites lichen	x		x	
Porites lobata	x		x	
Porites lutea	x		x	
Porites monticulosa	x		x	
Porites murrayensis	x		x	
Porites nigrescens	x		x	
Porites rus	x		x	
Porites solida	x		x	
Porites vaughani	x	x	x	
Siderastreidae				
Coscinaraea columna	x		x	
Coscinaraea exesa	x		x	
Coscinaraea wellsi	x		x	
Psammocora contigua	x		x	
Psammocora digitata	x		x	
Psammocora explanulata	x		x	
Psammocora haimeana	x	x	x	
Psammocora nierstraszi	x		x	
Psammocora obtusangula	x		x	
Psammocora profundacella	x	x	x	
Psammocora superficialis	x		x	
Total Species Recorded	**295**	**51**	**306**	
Total Genera Recorded	**58**	**27**	**60**	
Total Families Recorded	**14**	**11**	**14**	
Total New Records for Scott Reef	**8**	**2**	**8**	
Total New Records for WA	**5**	**2**	**7**	
Total New Records for Australia	**0**	**2**	**2**	