Smithsonian Institution

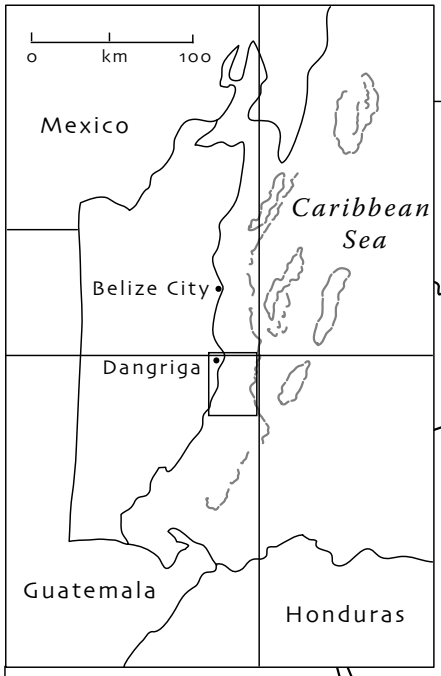
CCRE REPORTS 2006

Caribbean Coral Reef Ecosystems • National Museum of Natural History

August 2007

Carrie Bow Research Area

with most Cays named *revised 8/2004*



Dangriga

Columbus Cay
Mosquito Cay
Sandfly Cay
Hutson Cay
Cross Cay
Garbutt Cay
17˚00'N
Columbus Reef
16˚55'N
Tobacco Range
Tobacco Cay
Coco Plum Cay
Man-o'-War Cay
Tobacco Reef
Ragged Cay
Twin Cays
Blue Ground Range
South Water Cay
Carrie Bow Cay
Curlew Bank
Sittee Point
Sapodilla Lagoon
Stewart Cay
Patch Reefs & Sand Bores
Wee Wee Cay
16˚45'N
Spruce Cay
South Cut
Douglas Cay
Elbow Cays
Riversdale
Pelican Cays
N mag.
Manatee Cay
Cat Cay
Jonathan Point
Quamino Cays
Channel Cay
Lagoon Cays
Patch Reefs & Sand Bores
False Cay
Crawl Cay
False Point
16˚35'N
Tarpum Cay
5 km
Bakers Rendezvous
Rendezvous Cay
Gladden Cays
88˚15'W
88˚05'W

Smithsonian Institution

CCRE REPORTS

2006

National Museum of Natural History
Caribbean Coral Reef Ecosystem Program
Washington, D. C. 20013-7012

August, 2007

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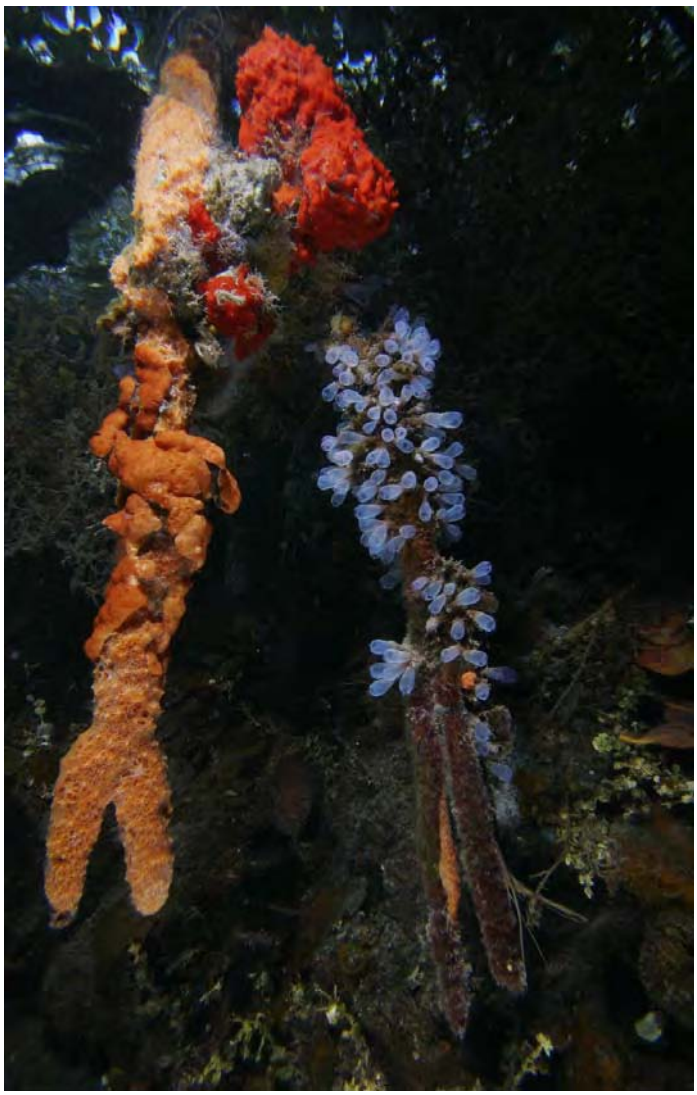
CCRE News 2006

Marine Science in Belize.

Klaus Ruetzler and three Smithsonian colleagues participated in the first Belize National Marine Science Symposium in Belize City, January 2006. The conference brought together over 50 scientists, conservationists, and fisheries experts working on marine organisms from reefs, seagrass meadows, mangroves, and blue water, including commercial species and farming. The participants came primarily from Belize, Canada, UK, and USA.

CCRE was represented by four papers, given by the authors: Ilka (Candy) Feller, SERC: Impact of nutrient over-enrichment on mangroves; Susan Richardson, NMNH: Ecology of epiphytic foraminiferans on seagrass; Martha Robbart (formerly CCRE): Population recovery of corals, genus Agaricia. Klaus Rützler, CCRE/NMNH: Caribbean Coral Reef Ecosystems: 30 Years of Smithsonian Marine Science.

CCRE staff and associates also contributed eight posters: María Cristina Díaz & Klaus Rützler (NMNH): Sponges as Indicators of reef health; Sandra Duran, Klaus Rützler & Valerie Paul (SMS & NMNH): DNA barcoding in sponges; Sandra Duran & Klaus Rützler (SMS & NMNH): Ecological speciation; Maria A. Faust (NMNH): Dinoflagellates of Twin Cays; Julie H. Mounts, Carole C. Baldwin & David G. Smith (NMNH): Digital photography of fish larvae; Thomas B. Opishinski (Interactive Oceanographics & CCRE): An automated real-time meteorological and oceanographic monitoring system; Mark W. Vandersea, R. Wayne Litaker, Steven R. Kibler, Maria A. Faust & Patricia A. Tester (NOAA & NMNH): Gambierdiscus: linking taxonomy and genetics (dinoflagellates); Mark W. Vandersea, Missy A. West, Steven R. Kibler, Maria A. Faust, R. Wayne Litaker & Patricia A. Tester (NOAA & NMNH): Phylogenetic relationships among dinoflagellates.



Later in the year (November 2006) D. Scott Taylor represented CCRE at another international meeting in Belize City, the 59th annual symposium of the Gulf and Caribbean Fisheries Institute. He and colleagues presented papers on the rich ichthyofauna of the mangal of offshore cays; and the adverse impact of mangrove removal on mangrove fish assemblages.

Hosting visitors and special projects.

Many travelers visit Carrie Bow when they are in the area, usually staying in guest houses on nearby South Water Cay, and get a brief tour of our facilities and a review of ongoing projects. This year was particularly busy, as we were called on by groups of about 90 Smithsonian Associates, some 30 Sierra Club members, and 14 North Carolina teachers sponsored by the N. C. Museum of Natural History. We also hosted a shark and whale census conducted by a group under the direction of Rachel Graham, a Dutch "Discovery" TV group filming a project on brittlestar biophysics by our collaborator Gordon Hendler (Los Angeles County Museum), and a picnic for the United States Ambassador to Belize and about 35 members of his staff.

Ilka (Candy) Feller (SERC) provided guidance to a visiting team who wrote (Anke Sparmann) and photo-illustrated (Christian Ziegler) an article for GEO, a widely-distributed German popular science magazine. This contribution (published in July 2006) was titled (in translation) Mangroves, border protectors between land and sea; it describes the biodiversity and unique properties of Twin Cays and other near-by mangrove communities and decries the sad decline of this precious resource by anthropogenic impact through shrimp aquaculture, pollution, and clear cutting by developers for vacation housing.

Flashbacks

1971 • National Museum of Natural History's I.G. Macintyre (geology & sedimentology), W. Adey, P. Kier, T. Waller (paleobiology), A. Dahl (botany), A. Antonius (postdoctoral fellow, invertebrate zoology), M. Rice, and K. Ruetzler (invertebrate zoology) found the program Investigations of Marine Shallow Water Ecosystems (IMSWE).

1972 • IMSWE search party identifies Carrie Bow Cay on the barrier reef of Belize as ideally located and affordable site for long-term, collaborative field research on tropical coastal ecosystems
• Establishment of principal reference transect across the Belize barrier reef just north of Carrie Bow Cay.

1974 • Hurricane Fifi destroys laboratory structures, uproots coconut trees, and reduces the surface area of Carrie Bow Cay by about one third, to 0.4 ha.

1975 • EXXON Corporation provides grant for study of the coral reef ecosystem at Carrie Bow Cay.
• Marine and terrestrial post-hurricane surveys.• Establishment of all-manual meteorological station.

1976 • Refinement and calibration of profiles and maps with the aid of vertical aerial photographs taken by Royal Signals Detachment helicopter • Introduction of aerial photography by helium balloon for community mapping
• Submersible tide recorder installed at Carrie Bow Cay concrete dock.

1977 • Field trip to Carrie Bow Cay by participants of the Third International Coral Reef Symposium.• Aerial and underwater surveys expanded to cover the entire barrier reef of Belize • Geology team drills first cores to determine reef history • EXXON's The Lamp publishes article on company-sponsored research at Carrie Bow Cay ("Where seaworms glow..").

1978 • Hurricane Greta destroys Carrie Bow Cay field station.

1979 • Post-hurricane survey and rebuilding of laboratory with several improvements • Count of participating scientists and of published scientific contributions both pass the 50 mark; 23 scientific institutions are now collaborating with NMNH.

1980 • EXXON Corporation funds new initiative: comprehensive study of a western Atlantic mangrove swamp ecosystem, now known as SWAMP (Smithsonian Western Atlantic Mangrove Program)
• Mapping of Twin Cays, principal site of SWAMP, by aerial photography and ground truthing.

1981 • Initiation of Art in a SWAMP project where scientific illustrators and scientists collaborate in analysis and picto rial rendition of mangrove communities in time and space • Employment of H. Edgerton underwater time-lapse camera with strobe light (on loan from the inventor) to record day-night activity in benthic communities
• Vibracoring at Twin Cays to determine internal structure and development.

1982 • Publication of The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, 1: Structure and Communities. Smithsonian Institution Press (K. Ruetzler & I.G. Macintyre, eds.). 1983 • New weather protected and enlarged seawater system for laboratory experiments installed on Carrie Bow Cay • Series of extremely low tides at noon time were observed to have catastrophic effects on reef and mangrove organisms.

1984 • First automated weather station installed at Twin Cays • Cooperation with Belize Government identifying coastal marine areas suitable for natural resource conservation • Busiest year since program start: 8 months con tinuing laboratory operation for 45 research staff.

1985 • First year of operation of Caribbean Coral Reef Ecosystems (CCRE), a new program of the National Museum of Natural History. It replaces the old IMSWE project and supplements the ongoing SWAMP program which is supported by a renewed annual grant by the EXXON Corporation.

1986 • Renovations on Carrie Bow Cay to accommodate dry-laboratory space, added living quarters, and boat, diving, and laboratory equipment • Mangrove vegetation map for Twin Cays completed • Published scientific contributions pass the number 200.

1987 • Record visitation of Carrie Bow laboratory, 120 total: 90 scientists and assistants; others dignitaries, including the Prime Minister of Belize, Smithsonian administrators, and media people working on documentaries and news-related productions • Continued facility renovation, including addition of solar photovoltaic system, large seawater tank, twofiberglass whalers, fluorescence microscope, and time-lapse video recorder with underwater camcorder.

1988 • Mangrove workshop for 37 EXXON-SWAMP scientists at Solomons, Maryland, entitled A Mangrove Ecosystem: Twin Cays, Belize.

1989 • Science as Art exhibit at the Smithsonian's S. Dillon Ripley Center displays scientifically important and aesthetically pleasing products from SWAMP mangrove research, such as community drawings, paintings, photographs, and sculpture-like epoxy casts of soft-bottom animal burrows • Vandalized and malfunctioning weather

station reconditioned and relocated to the Carrie Bow field laboratory • Mounting problems with anthropogenic stresses at research sites, such as heavy tourist visitation, garbage dumping, and clear-cutting mangrove trees.

1990 • CCRE-SWAMP program represented at first Caribbean Coastal Marine Productivity workshop, Jamaica, CARICOMP is a program for Caribbean-wide monitoring of environmental quality in reefs, mangroves, and seagrass meadows.

1991 • Belize Forestry Department helps stopping disturbances to SWAMP research sites. Belize Department of Natural Resources reviews legislation with intention of declaring Carrie Bow Cay - Twin Cays area protected research site • CCRE-SWAMP program staff participates in developing Belize Tropical Forestry Action Plan and helps designing Institute for Ecology to be based in Belmopan.

1992 • CCRE-SWAMP researchers produce video documentary on mangrove swamp biology • Unprecedented, severe problem with hydrozoan stings to snorkelers and divers in the Carrie Bow area traced tomicroscopic siphonophorans • CCRE-SWAMP staff and Belize Fisheries Department and Agriculture representatives conduct first workshop for Belize high-school teachers entitled Mangrove Conservation through Education • CCRE-SWAMP lecture series started in Belize City, co-hosted by Belize Audubon Society • CCRE officially joins the CARICOMP network and initiates monitoring program.

1993 • Belize Ministry of Natural Resources grants rights to Twin Cays for mangrove research • Launching of new 8 m (25 ft) research vessel Physalia, funded by a grant from the U. S. National Science Foundation, extends research radius over most of central and southern Belize • Ivan Goodbody pioneers surveys of Pelican Cays, a tunicate heaven at SSW of Carrie Bow.1994 • Start of collaborative surveys and experimental projects in the Pelican Cays • Pelican Cays workshop, co-hosted by Candy Feller (SERC), at Edgewater, Maryland.

1995 • Finalized lease with the Villanuevas of Placentia to southern portion of Northeast Cay, Pelican group, to establish a field base for future studies • Malcolm Spaulding develops plans for new integrated environmental sensing system with radio- telemetry linkto the University of Rhode Island's COASTMAP network.

1996 • Installation by Tom Opishinski of self-contained Endeco-YSI-Campbell monitoring station of meteorological and oceanographic parameters and hookup to Internet • Visit of field party from 8th International Coral Reef Symposium, Panamá.

1997 • Celebration of the 25th birthday of the Carrie Bow Marine Field Station • New U. S. National Science Foundation grant allows purchase of a second 8-m (25 ft) boat to back up the heavily used Physalia (under construction) • International team of seven expert systematists conduct workshop at Carrie Bow Cay to quantify the unusually high sponge diversity of the Pelican Cays • Number 500 reached of CCRE scientific contributions • Carrie Bow Field Station, including laboratories, weather station, kitchen, and living quarters is consumed by an accidental electric fire which was apparently sparked by a short in the wiring and aided by dry, termite-riddled lumber and strong northerly winds. Luckily, no-one was hurt.

1998 • Island clean-up and design for new field station completed. Construction work initiated but delayed by flooding and coastal erosion from hurricane Mitch • Completed editorial work on CD-ROM containing over 100 representative CCRE scientific papers that resulted from research at Carrie Bow Cay • Cosponsored Smithsonian (STRI) exhibit Our Reefs –Caribbean Connections in Belize City. Contributed large poster describing 25 years of CCRE coral reef research in Belize • Serious coral bleaching and die-off on reefs off Carrie Bow and Pelican Cays observed, partly caused by hurricane Mitch.

1999 • Rededication ceremony for the new Carrie Bow Marine Field Station, in August • BBC team (Bristol, UK) films segments for its Blue Planet TV series, including (with E. Duffy) eusocial shrimps living in sponges.

2000 • Publication of Natural History of Pelican Cays, Belize, in Atoll Research Bulletin (Macintyre & Ruetzler, eds, 2000) • Replacement of environmental monitoring station lost in the 1997 fire • Initiation of Twin Cays Biocomplexity Study funded by an NSF grant (to I. Feller & colleagues).

2001 • Completion of 3-room cottage over the eastern shore of Carrie Bow Cay • Hurricanes Michelle and Iris (October) barely miss Carrie Bow Cay, causing some damage to buildings and heavy beach erosion and devastate (Iris, in particular) large areas in southern Belize • Signing of MoU with Belize Fisheries Department officially acknowledging the Carrie Bow Marine Field Station as a nationally recognized laboratory • Publication of Golden (50-year anniversary) issue of Atoll Research Bulletin recognizing prominent coral reef scientists through their autobiographies, several of them participants in the CCRE Program.

2002 • Founding of the Smithsonian Marine Science Network (MSN), incorporating the CCRE Program and the Carrie Bow Marine Field Station • Number 600 reached of CCRE scientific contributions • Ranger Station established on southeast Twin Cays by Belize Fisheries Department to oversee South Water Cay Marine Reserve.

2003 • Cristián Samper, recently appointed director of the Smithsonian's Natural History Museum, visits the Carrie

Bow station in July, makes dives on the barrier reef, and snorkels in mangroves habitats • Hurricane Claudette threatens Carrie Bow (July) and necessitates temporary evacuation • Smithsonian Secretary Larry Small visits the Carrie Bow lab in December and dives on the reefs • Twin Cays Mangrove Biodiversity Conference is held at Ft. Pierce, Florida (December), convened by Klaus Ruetzler, Ilka Feller, and Ian Macintyre, and cosponsored by Valerie Paul of the Smithsonian Marine Station at Ft. Pierce.

2004 • CCRE Postdoctoral Fellowship established • Hurricane Ivan causes substantial coastal erosion of Carrie Bow Cay • Atoll Research Bulletin volume dedicated to Twin Cays Mangrove Biodiversity goes to press • Number 700 reached of CCRE scientific contributions • Carla Dietrich takes over from Michelle Nestlerode as CCRE research assistant • Addendum to MoU with Belize Fisheries Department signed, clarifying intellectual property rights and issues of bioprospecting sponge in particular • CCRE Program Administrator Marsha Sitnik (recently, administrative advisor) retires.

2005 • A total of 13 hurricanes formed this season that came to a close on November 30. Three category five hurricanes, namely: Katrina, Rita and Wilma, caused substantial coastal erosion and damage to the, Carrie Bow facilities. All together, the record number of 25 named storms in the Caribbean area broke the previous record (from 1933) of 21 named storms • An external scientific review of the CCRE Program was conducted and resulted in a strong endorsement of the program's mission and accomplishments • Over 50 new CCRE scientific contributions were published.

2006 • The first Belize National Marine Science Symposium, cosponsored by Belize Fisheries and Forestry departments and the Hugh Parkey Foundation, took place and CCRE was represented with 4 talks and 8 posters, including a review of 35 years of Smithsonian Marine Science in Belize • CCRE hosted the U. S. Ambassador and 35 Embassy staff for a picnic, including a tour of the Carrie Bow lab facilities • More than 130 Smithsonian As sociates, North Carolina teachers, and members of the Sierra Club visited Carrie Bow for guided tours of facilities and ongoing projects • A film crew for a Discovery channel in The Netherlands worked at Car rie Bow to document Gordon Hendler's work on newly discovered brittle-star light-sensing organs • The CCRE program and the Carrie Bow Marine Field Station, along with all other Smithsonian marine programs and facili ties, took part in an external review ordered by the Smithsonian Undersecretary for Science; The efficiency and scientific productivity of the program and its field station received excellent marks.

Acknowledgements

The Belize Fisheries Department hosted our research and we are grateful to Ms. Beverly Wade and Mr. James Azueta for collaborating in scientific and educational activities and issuing permits. The owners and staff of Pelican Beach Resort in Dangriga provided logistical support for our fieldwork; Therese and Tony Rath of Dangriga helped with local management, photography, and computer backup for our weather station. Numerous volunteer managers helped run the field station and assisted in research activities and we are indebted to them for their many efforts: Jerry and Sandy Alanko, Sam Benson, Earl David, Ed Hunt, Joel Leavitt, Dan Miller and Claudette DeCourley, Keith Parsons, Gary Peresta, Tom Pezzella, Bert Pfeiffer, Craig Sherwood.

Back in Washington, we thank Marty Joynt and Carol Youmans (Department of Zoology) for administrative advice and preparation of many documents. Michael Lang and Laurie M. Penland supervised and ran all aspects of scientific diving at Carrie Bow. We also thank the Smithsonian offices of the Undersecretary for Science and the Director of National Museum of Natural History for continued support. Numerous colleagues inside and outside the Smithsonian Institution contributed grants funds and homebase to facilitate our CCRE program. The CCRE program is supported in part by the Hunterdon Oceanographic research Fund.

Research Projects

Biodiversity and its Links to the Ecosystem

Algae

Biodiversity of *Gambierdiscus* harmful dinoflagellates in the Belizean coral reef mangrove forest

M. A. Faust

1. Characterizing the Biodiversity and Habitat Preferences of *Gambierdiscus* species

Our research has identified natural eutrophication, lack of turbulence, and reduced vertical mixing to be responsible for harmful and non-harmful dinoflagellate bloom occurrences in the Belizean Central Lagoon. Two mangrove ponds protected from wind act as a reservoir for harmful and toxic dinoflagellates, *Coolia*, *Gambierdiscus*, *Ostreopsis* and *Prorocentrum*. Assemblages of dinoflagellates were photosynthetic site specific and species-specific. Dinoflagellates recognized in Douglas Cay belonged to the genera *Ceratium*, *Dinophysis*, *Gambierdiscus*, *Gonyaulax*, *Lingulodinium* and *Protoperidinium* species, whereas in Twin Bays *Bysmatrum*, *Coolia*, *Prorocentrum*, and *Protoperidinium* species occur. Bloom cell populations were known toxins-producing benthic *Gambierdiscus* and *Prorocentrum* species. The four benthic bloom-forming species in Douglas Cay were three species of *Gambierdiscus* and *Gonyaulax spinifera*, and in Twin Bays only one species, *Prorocentrum* sp. nov. Cell concentrations observed during the bloom were high, *Gambierdiscus* (429 cells L^{-1}) in the inner lagoon at Douglas Cay, Station DC^{-1}, (8/8/2006), and much lower during no bloom (48 cells L^{-1}), Station DC^{-2}, (5/16/2005); similarly, *Prorocentrum* bloom populations were high (881 cells L^{-1}) at Twin Bays, Station TB2, (4/28/2006) and much lower during no bloom (250 cells.L^{-1}) Station TB 2, (5/14/2005) respectively. Dinoflagellate bloom concentrations were 3-5 orders of magnitude lower in water collected outside Douglas Cay and Twin Bays than inside. The morphology of four bloom forming species is illustrated in SEM photographs. This pattern implies that natural eutrophication present in mangrove embayments favors selection of toxic bloom forming benthic dinoflagellates and conforms to the prediction of Margalef's Mandala. Protected mangrove ponds are potential source of harmful and toxic dinoflagellate blooms and thus source of ciguatera outbreaks (Faust et al. 2006. Abstract, Session Population Dynamics, 12th International HAB Conference, Copenhagen, Denmark).

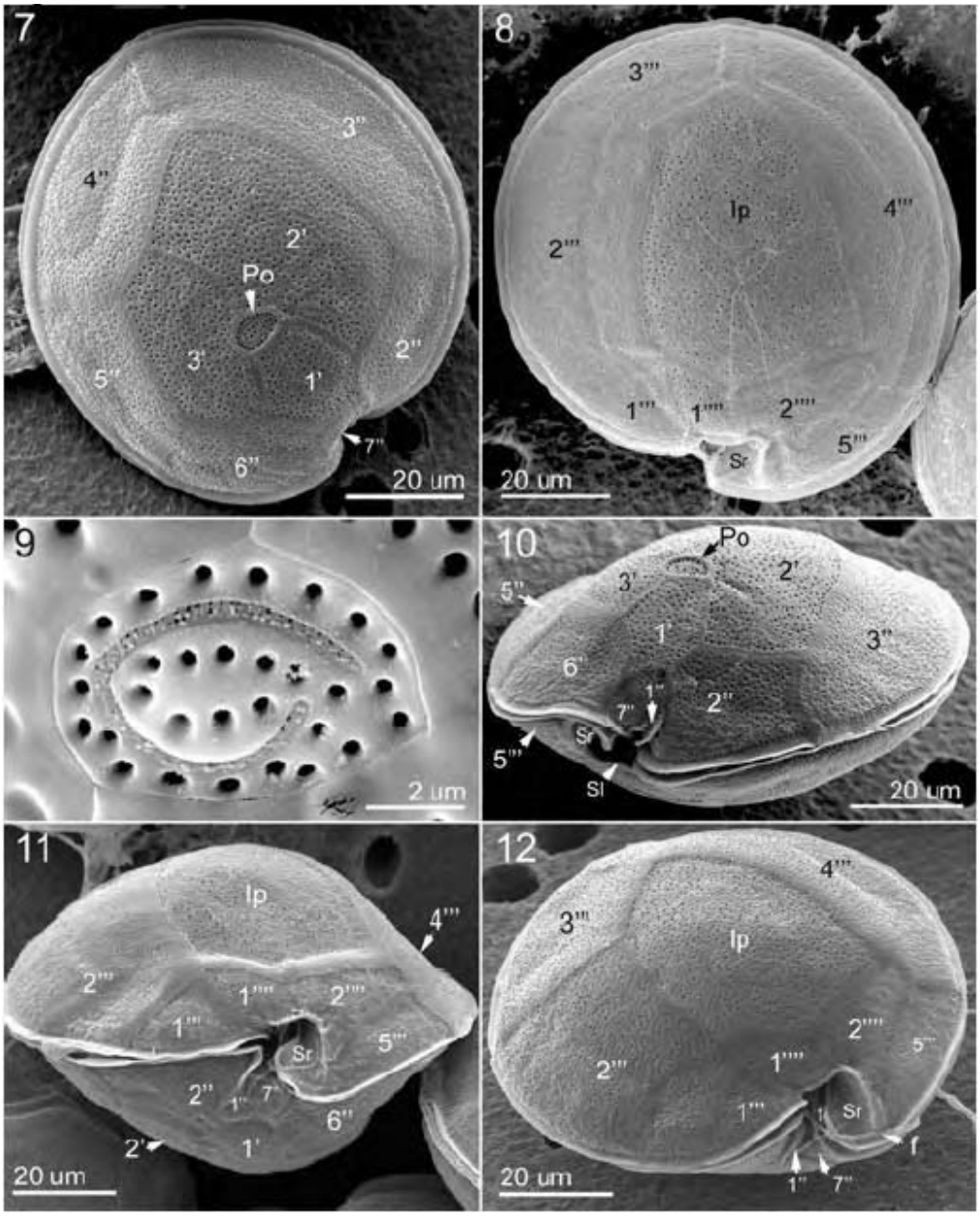
2. Taxonomy of *Gambierdiscus* including Five New Species: *G. caribbeanensis* sp. nov., *G. caroliniana* sp. nov., *G. carpenteri* sp. nov., *G. ruetzleri* sp. nov., and *G. tropicalis* sp. nov. (Gonyaulacales, Dinophyceae).

Phylogenetic analyses of both SSU and rRNA and D1-D3 LSU sequences as well as morphological differences, support the establishment of 5 new Gambierdiscus species: *G. caribbeanensis* sp. nov., *G. caroliniana* sp. nov., *G. carpenteri* sp. nov., *G. ruetzleri* sp. nov., and *G. tropicalis* sp. nov. Establishment of these species is supported by morphological differences and separate phylogenetic analyses of the small subunit and the large subunit D1-D3 region rRNA genes which included sequences derived from 54 isolates in cultures for all species except *G. toxicus*. *Gambierdiscus toxicus* sequence was derived from an epitype culture identified by Chinain et al. (1999). All five new species are photosynthetic and have am enhanced Kofoidian plate formula of Po, 3', 7'', 6c, 8s, 5''', 1p, and 2''''. Many of these new species are similar to each other and cannot be identified using light microscopy. These are instead more easily distinguished using species-specific molecular assays. These new species were genetically and morphologically distinct from known species, *G. australes, G. belizeanus, G. pacificus, G. polynesiensis*, and the epitype culture of *G. toxicus.* The SSU phylogenetic analysis further indicated that the genus *Gambierdiscus* is monophyletic and 11 species fall into 4 different lineages. Based on the number of new species that we identified it is apparent that the genus *Gambierdiscus* is a diverse multi-species complex that likely contains additional species.

Dinoflagellate diversity and abundance in Belizean coral reef-mangroves: A test of Margalef's Mandala

M. A. Faust, R. W. Litaker, M. W. Vandersea, S.R. Kibler & P.A. Tester

Toxic and non-toxic dinoflagellates are abundant in the waters of the Belizean Central Lagoon, Atlantic Barrier Coral Reef Mangrove Ecosystem. Dinoflagellates are costal and off shore planktonic, and benthic species. The most often bloom forming dinoflagellate observed are: *Bysmatrum caponii*, *Dinophysis caudata*, *Gonyaulax grindleyi*, *Peridinium quinquecorne*, *Gonyaulax polygramma*, *Gonyaulax spinifera*, *Lingulodinium polyedrum*, and *Pyrodinium bahamense* var. *bahamense.* Nineteen bloom-forming species were identified and half of those identified are known toxins producing species. A network of coral ridges of semi-enclosed ponds of typological diversity and complex ecology limit water exchange with the lagoon. The unusual hydrography of the mangrove embayments and nutrient input from natural sources enhance development of blooms. Bloom of *G. polygramma* may reach cell densities between 1 to 3 x 106 L^{-1}. Dissolved ammonium is the naturally produced nutrient at 0.1 to 6.0 µmole L^{-1} maintains the blooms of dinoflagellates. The above conditions influence the ability of cells to concentrate and proliferate into species-specific blooms that favor dominance toward dinoflagellate species. Margalef's Mandela predicts that marine environments with low turbulence and high nutrient inputs favor dinoflagellate growth. As a consequence this species shift may cause altered food web dynamics and the prevalence of toxins in the microbial food chain.



Does *Gambierdiscus toxicus* type material exist?

P. A.Tester, M. A. Faust, M. W. Vandersea, S. R. Kibler, M. Chinain, M. J. Holms, W. C. Holland & R. W. Litaker

Gambierdiscus species have a pan tropical distribution and some produce ciguatoxins which concentrate in marine food web, causing ciguatera fish poisoning. *Gambierdiscus* cells are typically referred to as either *Gambierdiscus toxicus* or *Gambierdiscus* sp., the genus encompases a diverse multispecies complex. This species diversity is generally underappreciated in most ecological studies. Our research was undertaken to better characterize the *Gambierdiscus* species both morphologically, using SEM and calcofluor staining, and molecularly SSU through-D1-D3 LSU rRNA sequences. The molecular and morphological data support the existence of at least five new species, plus five or six currently

described species. The major problem was with *G. toxicus*, which could not be resolved because type material was unavailable. Also, despite an excellent description of the genus morphology in the original paper, the large range in cell sizes and multiple collection sites for the type material causes us to ask if the type *G. toxicus* description included multiple species. We would like to open discussion on whether type material exists or if a new, molecularly well defined, type species should be established. Once ecological studies include species level identifications, the differences in distribution, abundance and toxicity of CFP outbreaks may be better understood.

Toward integrating molecular data into the process of recognizing new dinoflagellate species

R. W. Litaker & P.A. Tester

Dinoflagellate taxonomy is based on morphological criteria that are inherently more difficult to obtain than are corresponding DNA sequence data. This result in the rapid accumulation of sequence information indicating many more species exist than can be adequately described given the extant morphological data. Currently, no method exists for systematically categorizing these sequences into potential species groups for use in ecological studies or for taxonomic characterization. We examined whether genetic distances among ITS1/5.8S/ITS2 rRNA sequences could be used for this purpose. The analysis involved identifying sequences from 81 dinoflagellate species to determine if uncorrected genetic distances (p) above a certain level consistently correlate with known species boundaries. For a diverse assemblage of dinoflagellate species, the within species genetic distances between ITS1/5.8S/ITS2 copies (p=0.000-0.021 substitutions per site) were consistently less than those observed between species (p=0.042-0.580). Our results indicate that a between species uncorrected genetic difference >0.04 could be used to delineate most dinoflagellate species, including cryptic forms. Recently evolved species, however, may have ITS p values <0.04 and require more extensive morphological analysis, in combination with rRNA monophyly as a grouping criterion, to resolve. The overall significance of the correlation between morphology and molecular sequences is still under study.

Tropical mangrove embayments: Lessons in natural eutrophication and implications for dinoflagellate abundance

R. W. Litaker

Belize is home to the largest barrier reef in the western hemisphere. The reef complex is bounded by the azure Caribbean Sea and encloses a wide (10-40 km) central lagoon characterized by patch reefs and small mangrove islands. Much to our surprise some of the mangrove islands with shallow embayments have rich phytoplankton communities supported by rapid regeneration. A unique combination of island morphology, wind sheltering and low tidal amplitude favors accumulation of material and limits flushing in these embayments. Typically, these sheltered mangrove embayments are less than 3 meters deep with a shallow sill, which limits exchange with surrounding waters. Our study focused on a shallow, productive mangrove embayment at Peter Douglas Cay off south central Belize. At Douglas Cay the chlorophyll a concentrations were 20 fold higher than in the surrounding oligotrophic lagoon. In a study to examine the productivity of this mangrove embayment, a YSI Sonde 660 was moored for periods up to seven days to record chlorophyll fluorescence, salinity, temperature, PAR and oxygen. In addition wind speed and direction and rain fall were recoded at a nearby location (Carrie Bow Cay). During a period of low rain fall and high, consistent winds a very regular daily cycle of productivity, indicated by chlorophyll a and oxygen production, was noted. Daytime oxygen saturation varied between 20 and 40 percent and was maximal at or near noon. However, the highest oxygen values did not coincide with the mid day chlorophyll peak or even lag it by several hours. After sunset (1900 hours) the oxygen saturation increased sharply with a maximum of 50 to 75 percent saturation at midnight. Destratification, caused by cooling of the surface waters after sunset, resulted in a daily turnover that oxygenated the entire water column. Benthic, rather than water column, productivity was the source of the high night time oxygen levels. The high regeneration rates and prevailing hydrodynamic regime provided an ideal environment for the development of rich dinoflagellate community. Many of these species are potential ciguatoxin producers. These embayments and their phytoplankton assemblages represent a natural eutrophication that provide many insights into phytoplankton species shifts and potential increases in ciguatoxin production that may oc-

cur in this region with increased anthropogenic nutrient inputs. These results are consistent with the predictions of Margalef's Mandala. An integral part of this project has been the taxonomic and molecular characterization of ciguatera producing dinoflagellates. At present, relatively little is still known about the taxonomy of this group and the inter species variations in toxicity. For the past three years we have been integrating the SEM technologies available at the Smithsonian with the cell culture and molecular biology capabilities at NOAA to provide definitive molecular identifications for the isolated of potentially ciguatera producing dinoflagellates we have obtained from Belize. Once these isolates are fully characterized taxonomically, their toxin production characteristics will be determined along with development of molecular quantification techniques that will allow accurate estimates of abundance and distribution of individual species in the field.

Mangrove Algae: The genus *Caloglossa* (Delesseriaceae, Rhodophyta) in Twin Cays, Belize, with an emphasis on its biodiversity in Central America

J.N. Norris, C.F.D. Gurgel, D.M. Krayesky & S. Fredericq

Caloglossa (Rhodophyta): Collections were successfully made of *Caloglossa*, entangled with another red alga, *Bostrichia*, on mangrove prop roots from the high-intertidal to shallow subtidal using snorkle gear in the mangrove habitats of Twin Cays, South Water Cay, Man-o-War Cay and the Pelican Cays. These important specimens of *Caloglossa* will enable us to complete the morphological, DNA sequence analysis and phylogenetic analyses necessary to resolve to taxonomic status and distribution of the Caribbean species.

Benthic Macroalgae: Efforts also focused on collecting other benthic marine macroalgae, primarily Rhodophyta, for taxonomic and phylogenetic and phylogenetic studies. Specimens were collected from the shallow subtidal to depths of 40 m. using scuba, and studied using microscopes at the CBC Marine Lab., photographed (using digital cameras), and then liquid-preserved in 5% buffered Formalin-seawater, with portions dried in silica-gel for subsequent DNA analyses. Voucher specimens will be deposited: Algal Collection US National Herbarium (NMNH, Smithsonian).

Other studies (examples of studies we are starting as a result of this extremely productive expedition):

-- Molecular Systematics of the Red Algal Family Liagoraceae in Belize. Fifteen samples of phenotypically distinct 'liagoroid' specimens, were photographed placed in silica-gel along with liquid-preserved vouchers of each molecular sample taken.

-- Global Phylogeoography of *Hypnea musciformis* (Rhodophyta). Population studies of *H. musciformis* sampled in Dangriga (= 20 specimens of separate individuals in silica gel and liquid-preserved). Molecular and phylogenetic analyses will augment on the following ongoing projects: 1) SMS Postdoctoral Fellowship research of C.F.D. Gurgel on the phylogeography of H. musciformis along both coasts of the Florida Peninsula; 2) allow testing of the influence of NE Brazil upwelling region and the Amazon River on the phylogeography of *H. musciformis* in the Western Atlantic (Is the Amazon River a ecological barrier isolating these populations?); and, 3) comparison with the phylogeography and phylogenetics of the invasive populations of *H. musciformis* in the Hawaiian Islands.

-- Biodiversity of the red alga genus *Hypnea* in the western Atlantic.

Collections of other species of *Hypnea* (silica gel + herbarium vouchers) will complement the collections needed the current Smtihsonian Postdoctoral research underway on the molecular systematics and biodiversity of the genus *Hypnea* in the northwestern Atlantic.

-- The brown alga *Lobophora variegata*-complex: one or more species? Samples (silica gel + herbarium vouchers) of were prepared that encompass all three, very distinctive, phenotypes. Do they represent a singles (as currently accepted), OR is there more than one species in this morphological-complex. This will enable us to test their phylogentic relationships and taxonomic status.

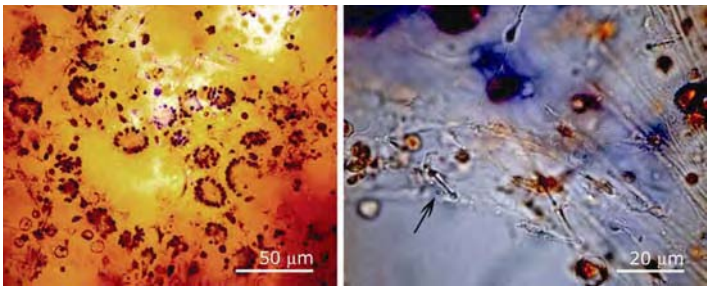
-- Phenotypic variation in the economically important red alga Eucheuma isiformis. Collections of distinct phenotypes (silica gel + herbarium vouchers) will enable testing of the morphological and taxonomic boundaries among different varieties and morphs using molecular DNA sequencing techniques.

Porifera

Iotrochota revisited: A new sponge from Belize (Poecilosclerida, Iotrochotidae)

K. Rützler, M. Maldonado, C. Piantoni & A. Riesgo

The systematics of tropical and subtropical western Atlantic species of *Iotrochota* is re-examined in light of discovery of an undescribed species. *I. birotulata*, the type species, is found to have more characters than previously assumed and is redefined with emphasis on a skeleton of spongin fibers containing stout, curved, styles and strongyles (category I) and



an interstitial spiculation consisting mainly of longer, slender, and straight, styles (II). *I. bistylata* is confirmed as a synonym of the above. The new species, named *I. arenosa*, differs by external morphology, strong mucus development, incorporation of sand, and interstitial spicules that are mainly long, straight strongyles. *I. atra,* thought to be a synonym of *I. birotulata*, is recognized as a separate species occurring exclusively in the Bahamas, and is found to be a senior synonym of *I. imminuta*; it is morphologically very similar to *I. birotulata*, but lacks birotulas and has a strongly reduced skeleton of megascleres (mostly one category of delicate strongyles). *I. agglomerata* is recognized as the forth distinct species for it has unusual color (orange), thinly encrusting habit, and special spiculation (styles with tylostylote modifications).

Annelida

Taxonomic status and distribution of *Lysidice* and *Nematonereis* species (Polychaeta, Eunicidae) and of other selected families (Sabellidae and Syllidae) in the Western Caribbean Sea: Do different habitats select for different species?

M. C. Gambi, K. Fauchald & A.Giangrande

Although the Eunicidae of the Western Caribbean Sea appears to be well studied (Fauchald, 1970), the taxonomic status of *Lysidice* and *Nematonereis* have not yet been evaluated. Systematic analyses of the approximately 30 species world-wide reported for the two genera combined have been singularly unsuccessful: despite the complex jaws, these are simple-bodied worms with few of the characters normally used in eunicid systematics to separate species.

The cryptic habit of both genera (within corals, seagrass and soft-bottoms) probably favoured their relatively high diversification especially in tropical areas, however, only a few species have been reported for the Western Caribbean (Salazar-Vallejo, 1996; Salazar Vallejo and Carrera Parra, 1997): *Lysidice ninetta* (sensu Gathof, 1984), and *Lysidice tortugae* Treatwell, 1921 described from a single, incomplete specimen, and *Nematonereis unicornis* Grube (sensu Gathof, 1984), which includes *N. hebes* Verril, 1900 described from Bermuda.

Previous observation on some material, associated to the seagrass *Thalassia testudinum*, suggested the possible occurrence of two new species (Gambi et al., 2003).

Among the Syllidae, the sub-family Syllinae, has been poorly investigated in the Western Caribbean respect to other sub-families.This group of syllids is very common both in corals and in association with sponges especially of the genus *Ircinia*, where analysis of previous material already revealed the presence of a new *Syllis* (Giangrande et al., 2002; Musco and Giangrande, 2005).

The aims of our research at Carrie Bow during this study period were:

1) collection of species to the genus *Lysidice* and *Nematonereis* in different habitats available near Carrie Bow Cay, aimed at the proper definition of their taxonomic status and at define possible niche separation among species, as well as other patterns related to habitat features, such as specimen size, sexual maturity and other morpho-functional features.

2) collection of species of the other selected families (Sabellidae and Syllidae) within various habitats (coral rubbles, different species of sponges, macroalgae), to increase the knowledge on the biodiversity of this group and define habitat selection of different species. The collection has been entirely conducted SCUBA diving by Gambi, Giangrande and Keel, and lasted from 10th to 16th of November for a total of 12 dives. After the 16th was not more possible to go at sea for collection due to bad weather conditions (strong winds and rough sea) and tropical storm warning (later transformed in hurricane "Gamma"). On the 19th the research team was forced to leave Carrie Bow Cay due to persistence of bad weather and hurricane warning.

Coral rubble and macroalgae, mainly of the genus *Halimeda*, were collected in various sites around Carrie Bow Cay, both in the lagoon (e.g., Wee Wee Cay, west side of Twin Cay, Blue Ground Range) and on the outer reefs in front of the CBC marine station, and at depths from 1 to 20 m. Various species of sponges (*Ircinia* sp., *Ircinia strobilina*, and the "fire sponge" *Tedania insignis*) were collected mainly in shallow coral rubble (1-6 m depth). *Thalassia testudinum* (seagrass) shoots were collected in various sites only within the lagoon and at depths from 1 to 8 m.

Although the period of research at the CBC station was shorter than planned, the collected material was plentiful obtained even considering thw high aim of the program. We obtained at least 5 morphotypes of *Lysidice* and one of *Nematonereis*. Some habitat selection between different species was clearly observed, in particular *Lysidice* sp. a, *Lysidice* sp. b and *Lysidice* sp. d, and *Nematonereis* sp. were exclusively collected in *Thalassia testudinum* sheaths where these worms burrow complex galleries within the sheath tissues. While *Lysidice* sp. c and *Lysidice cf collaris* were collected exclusively in corals rubbles, preferentially in deep sites of the "spur and grove" outer reef (15-20 m depth).

No specimens of *Lysidice* or *Nematonereis* were observed inside the studied sponges, or in very shallow (less than 3 m depth) coral rubble. Finally, it is interesting to note the occurrence of some mature specimens of both *Lysidice* sp. a and *Lysidice* sp. c, characterized by large eyes and the posterior body portion swelled and full of gametes. Some drawings were made using the optical microscope with camera lucida, and photographs through the stero-microscope were taken of selected species.

All material was first fixed in 4% formalin and then changed to 70% alcohol. Some specimens of the most abundant species collected were also fixed in absolute ethanol for DNA analysis.

As for the Syllidae and Sabellidae, many specimens were collected, especially those in association with coral rubble, macroalgae (*Halimeda* spp.), *Thalassia* shoots and sponges of the genus *Ircinia*. For most sponge specimens collected, the volume of the indi-

vidual was evaluated, and a piece of tissue was fixed for identification. In some cases the level of syllids colonization inside sponges was impressive, resulting in several hundred individuals in a few cm^3 of sponge volume. A small collection of Sabellidae was already analysed, revealing, together with some species already known for the area, the presence of two new species, one belonging to the Sabellinae subfamily, *Megalomma fauchaldi* n. sp. and another to the Fabriciinae subfamily, *Pseudoaugeneriella spongicola* n. sp., this latter represents a genus newly reported for the Caribbean Sea region (Giangrande et al., submitted).

Nemertine Worms

Diversity of interstitial and symbiotic nemerteans from the vicinity of Carrie Bow Cay

J. Norenburg

Jon Norenburg (SI), two PhD students (Megan Schwartz, George Washington University, and Cynthia Santos, University of Sao Paulo, Brazil), research collaborator Joan Ferraris (NIH, 1 week) and research assistant Barbara Littman (SI), were on Carrie Bow Cay for two weeks in June. The primary focus was training the students and collecting specimens for their research projects. Dr. Ferraris collaborated in preparing specimens for molecular studies.

We collected 117 specimens, representing 44 putative species, from a broad selection of habitats but most of the diversity was in rubble collected in 5 to 20 meters depth on the forereef and in the lagoon adjacent to CBC. Almost all are unknown or undescribed species. Some we had encountered on a previous trip but about 30 species were new to us. As usual, most species are represented by only one, two or three specimens and many of those were not sexually mature, which they need to be for taxonomic work. About 10 species were represented by 5 or more specimens and we started taxonomic work on these; four were recently described. We have sketches, detailed notes, and some sort of photographs for almost all species. These will migrate to the nemertean web site as appropriate parts of the site are developed. We have tissue samples for molecular data for almost all species, either a whole specimen or a piece taken from a single specimen. All other specimens were fixed for histology.

The molecular samples are the most important at this time, because they yield useful information even when it is not practical to do definitive taxonomic work with other specimens fixed for morphological studies. For instance, we have about 10 putative species or morphotypes that appear to be closely related and may actually be color morphs. We doubt that this is likely for all of them but we have no way of knowing without genetic analysis. We collected several juveniles of *Carcinonemertes* from 3 majid and 2 xanthid crab species not previously known as hosts, but were unable to obtain adults or significant specimens numbers. Worms from three of the hosts have been sequenced and appear to represent new species.

Crustacea

Taxonomy and population structure of commensal leucothoid amphipods from the Belize Barrier Reef

J. D. Thomas

In September, 2006 PI James Thomas and students conducted 14 SCUBA surveys of potential invertebrate hosts for leucothoid amphipods. During the September sampling period another new amphipod species was recorded from the sponge, *Lissodendoryx isodictyalis*. This brings the total new species discovered during this project to 14. Two species are described, reports on six are in press, and the remainder are in the process of being illustrated and described. Four new *Leucothoe* species inhabit interior canals of sponges; *Leucothoe barana* n.sp., *L. garifunae* n.sp., *L. saron* n.sp., and *L. ubouhu* n.sp. A remarkable new species, *Leucothoe flammosa* n.sp., nestles in the gills of six species of bivalve mollusks. A single species, *L. wuriti* n.sp., appears restricted to the branchial chamber of two species of solitary ascidians.

Extensive field collecting using specialized underwater collecting techniques enabled Thomas to document 43 new invertebrate host records for these taxa. Previously, no published records existed for invertebrate hosts of commensal *Leucothoe* amphipods.

Diversity of decapod crustaceans from Twin Cays, Pelican Cays, Carrie Bow Cay and adjacent intertidal to shallow subtidal waters

D. Felder, R. Lemaitre, R. Robles & J.Stake

Collections were focused on and immediately around Carrie Bow, Twin Cays, and shoals along S. Water Cay. Extensive collections of decapods (along with ancillary collections of stomatopods) were obtained toward production of the regional checklist which, as proposed, continues work begun by DLF and R. Manning in the early 1980's; the 2002 trip contributed extensively to a collections of color photographs for potential use in production of a regional guidebook to the decapod crustaceans, in an anticipated collaborative effort between DLF and RL. Over 1000 decapods crustacean photographs were taken by DLF in the present effort. Other project elements included the obtaining of genetic samples and larval stages for selected groups of burrowing thalassinideans (with associates) and porcellanids under study. Likewise, extensive collections of *Iridopagurus* were obtained for use in fresh dissection studies of gross anatomy and preservation for use in subsequent microscopy. These were essential to on-going investigations of structure, function and phylogenetic significance of hermit crab sexual tubes. At least one follow-up trip will be required for additional work on and around Twin Cays, especially nearshore and intertidally, if this area is to be adequately represented in the envisioned guidebook. While products of this trip will contribute to varied future publications, at least two phylogeny of the thalassinidean burrowing genus *Lepidophthalmus*, systematics of the commensal crab genus *Austinixa*) should be completed in the coming year.

Pisces

Adult specimens and comparative habitat data for a new species of *Emblemariopsis* chaenopsid blenny fish on the Curlew Bank

J. C. Tyler

The work by J. and D. Tyler on chaenopsid blennies around Carrie Bow Cay over the years has resulted in the descriptions of several new species of this group of hole-dwelling blennies and improved knowledge of their behavioral ecology: Smith et al. (1998), Tyler and Hastings (2004), Tyler and Tyler (1997, 1999). The completion of the Pelican Cays fish survey recorded the distribution of these blennies (Smith et al., 2003) off Belize.

On the basis of our previous work around Carrie Bow, we know that there is one additional undescribed species of the genus *Emblemariopsis* in shallow water there. In 2005 we collected two individuals, both juvenile males, of this new species in holes in mound corals to the north of the lab. The new species is in the group of species of *Emblemariopsis* having 13 pectoral-fin rays and an orbital cirrus. It differs from the other species in having a long and lobed orbital cirrus and in having at least the young males with only a moderately dark head and a relatively plain body.

During two weeks in May of 2006 we concentrated on trying to collect additional, and fully adult, specimens of the new species of *Emblemariopsis*. We easily collected three other species of *Emblemariopsis* (*pricei, ruetzleri, dianae*: specimens of each were preserved for molecular studies by other SI staff) at numerous locations around Carrie Bow and in the Pelicans and the Blue Ground Range, but we did not find the new species in these localities (including where previously found at CBC).

However, during the last two days at Carrie Bow in May 2006 we sampled for species of *Emblemariopsis* along the Curlew Bank (south of the former Curlew Cay). On those last two days we collected two more specimens of the new species, but, like the previous two specimens, both were juvenile males (13.1 and 13.2 mm SL), with paler heads and bodies than is the case of hole-dwelling young males in most of the closely related species of the genus.

On the very last day of our 2006 trip, we found an especially well-developed reef structure just to the south-west of the third cut in the Curlew Bank to the south of the former Curlew Cay. This isolated reef (at N. 16N44.971′, W. 88N05.287′) is distinctly west (or inside) of the cut and rises from a sandy bottom at 8-9 meters depth up very close to the surface. It has a high energy eastern side with good growth of elkhorn and staghorn corals, and abundant large mound corals higher up all along that leading edge of the reef. On the western side of the reef the mound corals remain abundant in a lower energy situation. At this exceptionally diverse reef we observed or collected five species of *Emblemariopsis*, including one of the juveniles of the new species.

We presume that fully adult specimens of the new species are to be found at this location along the Curlew Bank and we simply did not have sufficient time to find them, and also that our attention was focused on finding the very dark-headed males in holes in coral typical of most of the other species of *Emblemariopsis*. The hole-dwelling males of the new species probably have less dark heads protruding from their holes in the corals, and we must focus in the future on searching for this paler-dark-head appearance.

Thus, in order to obtain the fully adult males of the new species, and to search the coral surfaces and algal turf for females nearby hole-dwelling males, necessary for the proper description of the new species, we propose to concentrate on searching in the Curlew Bank, and especially within the diverse reef structure described above. We will also assess the habitats of the other species of *Emblemariopsis* (*pricei, ruetzleri, dianae, signifera, leptocirrus*) that we have observed or collected in the Curlew Bank area for comparison to that of the new species.

Genetic and morphological identification of the fish larvae of Carrie Bow Cay

C. C. Baldwin, D. G. Smith, J. Mounts, L. Weigt & A. Driskell

This report summarizes the results of our expedition to Carrie Bow Cay in March-April, 2006, the ninth in our ongoing study of the larvae of shore fishes of Carrie Bow Cay, Belize. As in our past visits, we collected larval fishes at night using a plankton net suspended from the dock on the ocean side of the island. During the daytime, we collected adult fishes using a variety of methods, including spears, hook and line, and traps. In Dangriga, we visited the local fish market and obtained several species there. We took samples for DNA analysis from as many species as possible, with an emphasis on species that we had not sampled before. We photographed every specimen from which tissue samples were taken and retained the vouchers for all but the large, easily identified adults and the very smallest larvae, which had to be sacrificed in their entirety to obtain DNA; even for the latter, however, we will have a photo voucher. We also continued our general photography program, with the objective of obtaining high-resolution photographs of as many species of Belizean fishes as possible.

Our program consists of a fusion of two distinct but related projects. One continues the larval-fish identification on which we have been working since 1992. The DNA sequences are helping us to match larvae with adults. The second project is part of FISHBOL (Fishes Barcode of Life) program, which aims to obtain diagnostic DNA sequences or barcodes for all living species of fishes. The Division of Fishes is partnering with the Laboratory of Analytical Biology in carrying out these studies. We combine the Fish Division's expertise

in fish identification with the LAB's expertise in DNA analysis.

Moon conditions were unfavorable during this trip, and plankton collections were generally light, but some good qualitative samples were taken. Over 450 DNA samples were taken, many from species not sampled before. We have now obtained DNA from approximately 250 of the approximately 500 known fish species in the area. The new samples will be processed within the next month or so, and we can then begin assessing the number of larval types successfully identified. In addition to providing identifications for several larval types, our 2005 DNA data also revealed some interesting patterns of genetic divergence that will require further taxonomic investigation.

An assessment of ichthyofaunal assemblages within the mangal Belize offshore cays

D.S Taylor, E.A. Reyier, C.C. McIvor & W.P. Davis

We assessed ichthyofaunal diversity within offshore mangrove cays in Belize during three, 2-wk surveys. Nine sampling gears were deployed in pre-defined micro-habitats: fringe, transition, dwarf red mangrove, internal creeks, ponds, and sinkholes. Water quality data (temperature, salinity, DO) were taken during most collections. A total of 2586 gear sets was completed and 8131 individuals collected, comprising 75 taxa. Minnow trap data from the various micro-habitats tested indicates some overlap in assemblages. Significant differences in water quality were also noted, with the fringe representing the most benign and the sinkhole the most harsh microhabitats, respectively. We also conducted extensive visual surveys around the fringe at a number of cays, tallying an additional 67 taxa. The fringe is the most diverse (128 taxa) and sinkhole least (12 species). An overall total of 142 taxa from 55 families has therefore been documented from the cays, and all but eight were found on Twin Cays alone. This figure is among the highest reported for oceanic mangroves in this biogeographic realm. Our comprehensive approach with a variety of gear-types in a wide range of micro-habitats, combined with visual observation, lends credence to the conclusion that most ichthyological species inventories for the mangal are commonly underestimates.

Paleobiology and Microevolution

Taphonomic process initiative and bottom-up versus top-down experimental controls on the Belize coral reef ecosystem

M. M. Littler, D. S. Littler & B. L. Brooks

Taphonomy – Thirty-one experimental replicates (rectangular sections of massive *Porolithon* and *Porites*) were harvested and assessed; i.e., 15 sets beyond the reef crest, 8 on the back-reef site and 8 on 15-m deep pinnacle site. This experiment is designed to address the "paradox of the coralline algae" which stems from the fact that although coralline algae are nearly always abundant (often dominant) in terms of cover on coral-reef systems worldwide, they only show up abundantly within fossil coral-reef deposits in relatively few formations. We hypothesize that this disappearance/alteration during fossilization is due to differential taphonomic processes. Many rock-boring and limestone altering creatures abound on coral reefs. For example, one of the most important groups of limestone altering organisms are the clionid sponges. Even though the calcite deposited by coralline algae is much denser/harder than the aragonite form of calcium carbonate produced by reef building corals, the former is precipitated within and between cellulose cell walls, which, even after death, may provide an energy source for the boring clionid sponges. This indeed appears to be the case, and potentially explains the mysterious disappearance of fairly massive/extensive deposits of coralline algal from the fossil record.

Nutrient experiments – The team also monitored the previously established 32 mini-reefs in a separate self-contained nutrient-enrichment experiment that partitioned the effects and interactions of slow-release soluble reactive phosphorus (SRP) versus dissolved inorganic nitrogen (DIN). The early results are rewarding and show an extremely complex set of competitive interactions that are specific to the individual species among functional groups and the presence of either SRP or DIN, in conjunction with the antecedent nutrient history of the system.

Collections and Field Guides – Our group collected over 268 numbered specimens in 2006 to augment the National Herbarium algal collections from various and diverse sites around CBC, Tobacco Range, Twin Cays and Pelican Cays. Over 624 in situ under-

water images of the collected specimens were recorded and labeled in support a revised edition of "Caribbean Reef Plants".

Molecular work – Sixty molecular samples quick dried in silica gel and frozen for future DNA experimentation (all of these samples backed-up with matching morphological collections).

Speciation in coral reef fishes: Causes and consequences of intraspecific diversity in wrasses (*Halichoeres*)

P. Wainwright

The starting point for this work is a species-level phylogeny of Caribbean *Halichoeres* and their closest relatives that has been prepared using DNA sequence data. The objective of this project is to answer whether sister species have a greater level of niche separation than expected by chance. If phylogenetically close relatives tend to be more different in resource use than expected by chance, then this will be interpreted as evidence of a strong role of niche separation during speciation. The null hypothesis is that resource use is no more likely to differ between close relatives than more distantly related species.

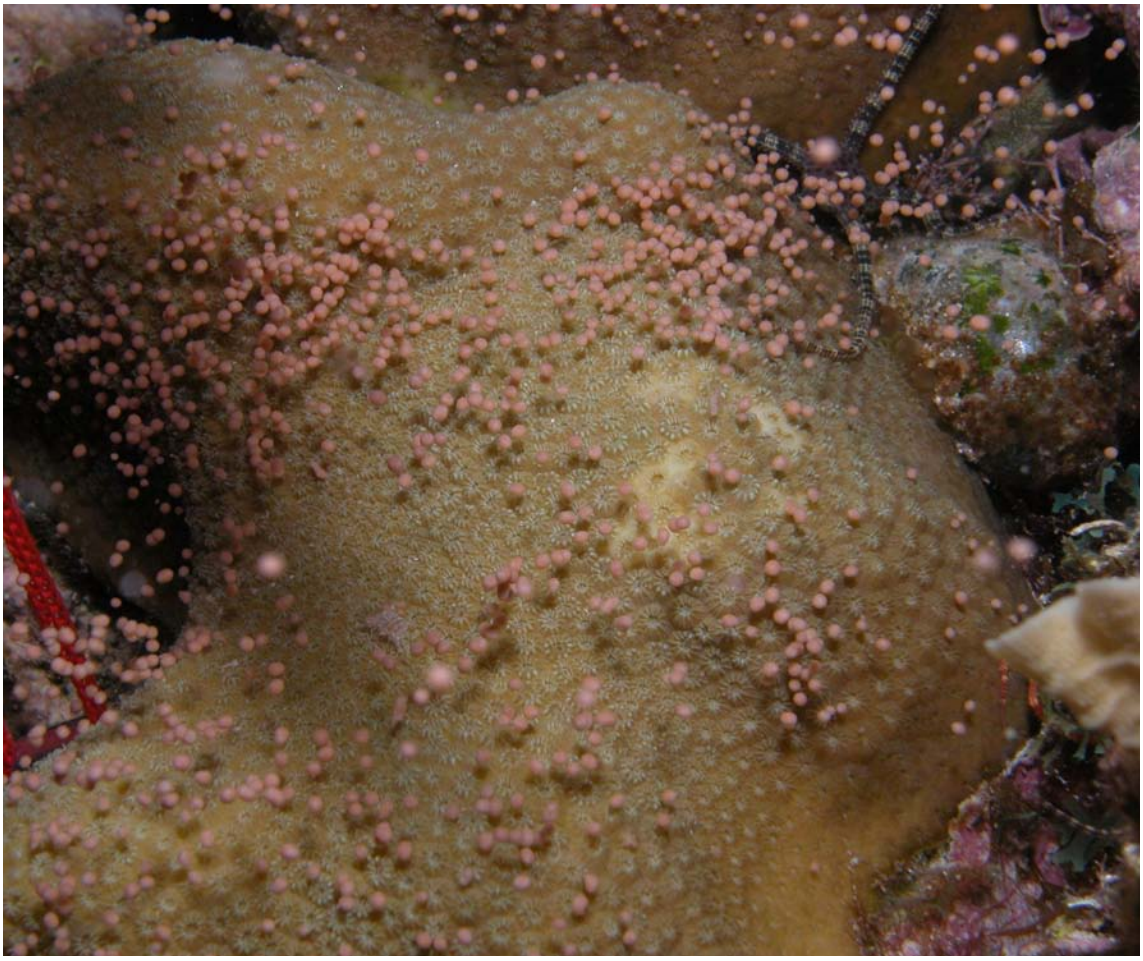
Reproductive and Developmental Biology

Spawning ecology of the *Montastraea annularis* species complex

D. Levitan & N. Knowlton

This was our second trip to Carrie Bow Cay, following up on our 2004 visit. During our 2004 trip we established two study sites, one deep (~50 feet) and one shallow (~15 feet) on reefs adjacent to Carrie Bow Cay. We made observations of species and site differences in spawning times and also collected laboratory data on interspecific compatibility of gametes among the three species in this complex. On this trip we collected three types of data.

(1) We observed spawning times for this group of species on the shallow site and because we had tagged corals in 2004, we were able to compare spawning times of specific colonies to determine the accuracy and precision of spawning times across years, for not only species, but also specific individual corals. We are finding remarkable precision across years in both species and individual spawning times. *Montastraea annularis* has a peak spawning time around 3:30 hours past sunset while *M. faveolata* peaks around 20 minutes later. Each species spawns over an



approximate 40 minutes interval. Within species, individuals observed to spawn in 2006 spawned within five minutes of the time recorded for 2004. This suggests a likely genetic component for a very precise spawning time.

(2) We pre-collected coral eggs and exposed samples of those eggs to reef water above the spawning event every 15 minutes before, during and after the spawning event. We were able to document the time course of sperm availability for both species of shallow water corals. For *M. annularis*, the species found at higher abundances, sperm are active and concentrated enough to result in high levels of fertilization for approximately one hour. For *M. faveolata*, the species found at lower abundances, this time interval is around 30 minutes. This provides important data on the likelihood of successful fertilization as a function of the abundance of corals.

(3) We conducted preliminary data on gamete diffusion from individual corals as well as individual gamete bundles per coral polyp. These data will be used in a model we have developed that will provide insight into likely levels of sperm availability as a function of coral density. These data and models will provide insight into not only the consequences of reduced coral densities on corals reefs to reproduction, but also will be used on another project aimed at investigating how spawning synchrony and sperm availability might result in sympatric speciation in corals and other externally fertilizing species.

Overall, this was a very successful trip. We are hopeful that we can set up a series of permanent study sites near and adjacent to Carrie Bow Cay. Long-term demographic data on coral along with long-term data on coral reproduction would be unique and important to our understanding of coral biology and coral reef health in the Caribbean.

Recruitment, growth, and ecological relationships of mangrove root encrusting bryozoans in the Pelican Cays, Belize

J. E. Winston

During the preliminary survey carried out in September 2005 (Winston in prep.) thirty-one species of bryozoans were found in mangrove communities in the Pelican Cays. Only in the large pond at Fisherman's Cay was the dominant bryozoan a common Caribbean fouling species, *Schizoporella pungens*. At Northeast Cay, Ridge Cay, Manatee Cay, and Cat Cay, as well as the small ponds at Fisherman's Cay, bryozoan species normally associated with cryptic reef habitats formed extensive colonies on the submerged hanging roots of red mangroves along banks or undercuts bordering the lagoon ponds. *Steginoporella magnilabris*, *Stylopoma*

"spongites", *Trematooecia aviculifera*, *Hippopodina feegeensis,* and *Rhynchozoon verruculatum* were dominant. However, presence and relative abundance of these reef species varied from cay to cay. The undersides of the overlapping thalli of the brown alga *Lobophora variegata* on vertical peat banks and attached to mangrove roots in well-shaded areas offered another type of bryozoan habitat, colonized by delicate branching and encrusting colonies. Eighteen species, including five undescribed species and one new genus, were found in the *Lobophora* habitat.

Review of the literature on mangrove-associated bryozoan faunas showed that in all other sites studied the bryozoan fauna consisted of eurytopic, shallow water or fouling species (Creary 2003, Farnsworth and Ellison 1996, Kolehmainen 1973, Sutherland 1980). The Pelican Cays appear unique in having cryptic reef species dominate at most locations. The goal of the future research is to determine what life history parameters or ecological relationships might explain this situation.

One of the most striking findings of the survey was that the dominant bryozoans on the roots formed colonies as large or larger than they do in cryptic reef habitats. How can these cryptic reef species grow so large out in the open on mangrove roots when there are so many apparent potential predators present? We saw numerous reef- and mangrove-associated fishes swimming among the roots, but did not observe any feeding on bryozoans. Perhaps this is not significant, as only a few fishes, like filefish, specialize on bryozoans as food, although on the reef, encrusting colonies can be grazed out of existence by coral feeding parrotfish. However, I plan to carry out feeding experiments to determine fish preference for or aversion to the dominant bryozoans. I will also search for the invertebrate grazers (limpets, chitons, urchins, and gastropods) responsible for much of the partial predation observed in the reef cryptic community and will document effects of their grazing or predation (or lack thereof) on bryozoan colonies.

Sexually reproductive colonies were present in all species that brooded embryos in ovicells, and in each case some ovicells contained developing larvae. To determine whether their growth rates in the mangrove habitat differ from the very slow rates shown for these species in cryptic reef habitats (Winston and Jackson, 1984) I will monitor recruitment of larvae and colony growth on root-like artificial substrata for at least a six month period. In addition, I will look for potential recruits by sampling the surface layer of water in the ponds, the water column adjacent to large colonies on roots, and water on the outer sides of the cays with a fine plankton net to capture the large and yolky bryozoan larvae of these species.

Another important factor controlling bryozoan distributions is competition for space. The dominant species are all known to be good competitors with long-lived colonies. In the preliminary survey they were observed to sometimes overgrow sponges and ascidians as well other bryozoans and solitary organisms. This will be examined further by detailed study of 10-20 colonies of each of the 5 dominant species.

Although the factors structuring this unique bryozoan community are undoubtedly complex I hope this project will give us a better understanding of its ecology, while the habitat still exists.

Gonopore sexing technique allows determination of sex ratios and helper composition in eusocial shrimps

E. Tóth & R. T. Bauer

An evaluation of the social organization and sexual system of eusocial species of *Synalpheus* has been hindered because it has not been possible to determine the sexual composition of colony helpers (workers). The external sexual characters typically used to sex caridean shrimps are lacking in *Synalpheus*. We used SEM sexing technique to determine the sexual composition of helpers in colonies of *Synalpheus regalis*, *S. rathbunae*, *S. chacei*, *S. rathbunae A*, and *S. filidigitus*. Colonies consisted of both sexes and sex ratios of helpers generally conformed to 50:50 female to male. Females were characterized by gonopores with U-shaped slits on the coxae of the third pereopods (first walking legs) while males had oval gonopore openings on the coxae of the fifth pereopods (third or last walking legs). In *S. chacei*, *S. filidigitus*, and *S. rathbunae A*, a few helpers were found that had both male and female gonopores (intersexes). All three reproductive females (queens) of *S. filidigitus* examined were intersexes. Sexing of helpers allowed us to test some hypotheses about sexual differences in helper morphology that might indicate task specialization (division of labor). Male helpers were not different from female ones in body size (except in *S. regalis*: males somewhat larger) and in fighting chela size. The lack of sexual dimorphism in these characters suggests no male–female specialization in colony

tasks such as defense. The presence of male and female helpers similar in size suggests that the sexual system of these eusocial species is gonochoristic, although protandry of some sort in *S. filidigitus* can not be ruled out. The intersexuality observed in a few individuals may be due to developmental anomalies, protandry, or even simultaneous hermaphroditism. Finally, the sexing technique allowed us to establish that new colonizers of unoccupied sponges in *S. rathbunae* are a single male and female of helper size.

Patterns of occurrence of late-stage pelagic fish larvae carried across the forereef of Carrie Bow Cay, Belize

K. S. Cole

A total of 7,707 late-stage (i.e. ready to undergo metamorphosis) fish larvae were collected on the fore reef of Carrie Bow Cay during a two week period in May 2006. This represents a 30% increase in the number of late-stage fish larvae collected during 10 weeks of sampling in 2005. The large size of the May 2006 collection suggests that this sampling period coincided with the annual spring peak in fish larval recruitment for the tropical western Atlantic. The majority of fish larvae collected belonged to one family, Gobiidae (n = 3,582, 46.5% of all larvae collected), and the majority of these belonged to one genus, *Ctenogobius* (n = 2,132, 27.7% of all larvae collected). Other well-represented taxa included the family Gerreidae (mojarras, n = 1,385, 18.0%), Scaridae (parrotfishes, n = 1,217, 15.8%), and Ophichthidae (spaghetti eels, n = 528, 6.9%). The numerical distribution of larvae collected over nights leading up to and following the new moon support a general trend, described in previous reports, of peak larval settlement of coastal and reef fishes occurring shortly before and directly after the night of the new moon in a lunar cycle.

Digital photography of living larvae of coral reef fishes of Belize

J. H. Mounts, C. C. Baldwin & D. G. Smith

Pelagic fish larvae were collected in a plankton net moored over a reef flat off Carrie Bow Cay, Belize. Larvae were transported into an adjacent laboratory where selected specimens were anesthetized and microscopically identified to morphological type if possible. One by one, the specimens were placed in a saltwater-filled glass tank and photographed. A glass plate supported by fishing line and weights was used to trap the specimen against the front of the tank. Very small specimens (< 10 mm) were placed in a depression slide, which was then covered with a flat microscope slide and trapped against the front of the tank. Photographs with a white background were taken using a Nikon D1X (5.47 megapixels) digital camera with a macro lens and synchronized dual Nikon SB-28X flash units mounted on tripods. The flash units helped to maximize the depth of field. Because the living larvae were transparent and most lacked strong color contrast, the photographs were purposely underexposed. The photographs were then adjusted using Adobe Photoshop to correct for the underexposure. Orange and yellow chromatophore patterns, which fade with conventional preservation methods, are being documented with this digital photography system and evaluated for their utility as characters in ongoing taxonomic and phylogenetic studies of tropical Atlantic shorefishes.

Ecology, Population Dynamics, and Ecophysiology

Water column structure and phytoplankton distribution in a mangrove embayment, Twin Cays, Belize

S. R. Kibler

Linkage between water column structure and phytoplankton distribution was investigated at the Lair, an isolated mangrove embayment at Twin Cays, Belize. Oceanographic profiles were collected in May 2004 along four stations situated between the Lair and the surrounding lagoon. Phytoplankton pigments were quantified by HPLC and the distribution of chlorophyll among algal taxa was estimated using ChemTax. Vertical structure was marked by diel stratification and export of dense bottom water in the afternoon and evening. Phytoplankton distribution was strongly depth dependent in the Lair and its entrance channel, where more than 65% of the chlorophyll was distributed along the bottom. Dinoflagellates dominated the phytoplankton at these two sites, representing >40% of the chlorophyll in surface samples. Microscopy further indicated many of these were ciguatera-associated benthic species. Continuous oceanographic measurements revealed a pattern of reverse vertical migration by phytoplankton, which moved upward in the water column in the early morning and descended before maximum irradiance. Migration occurred during minimum stratification, suggesting density gradients may regulate vertical distribution in the afternoon and evening hours. Spectral irradiance profiles showed UV was strongly attenuated relative to PAR, suggesting the near-bottom distribution and migration may be a mechanism by which cells avoid photic stress in surface waters.

Fine root respiration in the mangrove *Rhizophora mangle* over variation in forest stature and nutrient availability

C. E. Lovelock, R. W. Ruess & I. C. Feller

Root respiration uses a significant proportion of photosynthetically fixed carbon (C) and is a globally important source of C liberated from soils. Mangroves, which are an important and productive forest resource in many tropical and sub-tropical countries, sustain a high ratio of root to shoot biomass which may indicate root respiration could be an important component in mangrove forest carbon budgets. Mangroves are also often exposed to high levels of nutrient pollution from coastal waters. Here we assessed the magnitude of fine root respiration in mangrove forests in Belize and investigated how root respiration is influenced by nutrient additions.

Respiration rates of excised fine roots of the mangrove *Rhizophora mangle* L. were low (4.01 ± 0.16 nmol CO2 g-1 s-1) compared to those measured in temperate tree species at similar temperatures. In an experiment where trees where fertilized with nitrogen (N) or phosphorus (P) in low productivity dwarf forests (1 - 2 m height) and more productive, taller (4 – 7 m height) seaward fringing forests, respiration of fine roots did not vary consistently over fertilization treatments, or with forest stature. Fine roots of taller fringe trees had higher concentrations of both N and P compared to dwarf trees. Fertilization with P enhanced fine root P concentrations in both dwarf and fringe trees, but reduced root N concentrations compared to controls. Fertilization with N had no effect on root N or P concentrations. Unlike photosynthetic C gain and growth, which is strongly limited by P availability in dwarf forests at this site, fine root respiration (expressed on a mass basis) was variable, but did not show any significant enhancements with nutrient additions. Variation in fine root production and standing biomass over forests of different stature and with variation in nutrient availability are therefore likely to be more important factors determining C efflux from mangrove sediments than are variations in fine root respiration per unit mass.

Photosynthetic characteristics of dwarf and fringe *Rhizophora mangle* L. in a Belizean mangrove

J. M. Cheeseman & C. E. Lovelock

Twin Cays (Belize) is a highly oligotrophic mangrove archipelago dominated by *Rhizophora mangle* L. Ocean-fringing trees are 3–7 m tall with a leaf area index (LAI) of 2.3, whereas in the interior, dwarf zone, trees are 1.5 m or less, and the LAI is 0.7. P-fertilization of dwarf trees dramatically increases growth. As a partial explanation of these characteristics, it was

hypothesized that differences in stature and growth rates would reflect differences in leaf photosynthetic capacity, as determined by the photochemical and biochemical characteristics at the chloroplast level. Gas exchange and chlorophyll fluorescence were used to compare photosynthesis of dwarf, fringe and fertilized trees. Regardless of zonation or treatment, net CO^2 exchange (A) and photosynthetic electron transport were light saturated at less than 500 μm mol photons m-2 s-1, and low-light quantum efficiencies were typical for healthy C3 plants. On the other hand, light-saturated A was linearly related to stomatal conductance (gs), with seasonal, zonal and treatment differences in photosynthesis corresponding linearly to differences in the mean gs. overall, photosynthetic capacity appeared to be co-regulated with stomatal conductance, minimizing the variability of Ci at ambient CO^2 (and hence, Ci/Ca). Based on the results of in vitro assays, regulation of photosynthesis in *R. mangle* appeared to be acomplished, at least in part, by regulation of Rubisco activity.

Nutrient addition differentially affects ecological processes of *Avicennia germinans* in nitrogen vs. phosphorus limited mangrove ecosystems

I. C. Feller, C. E. Lovelock & McKee

Nutrient over-enrichment is a major threat to marine environments, but system-specific attributes of coastal ecosystems may result in differences in their sensitivity and susceptibility to eutrophication. We used fertilization experiments in nitrogen (N)- and phosphorus (P)-limited mangrove forests to test the hypothesis that alleviating different kinds of nutrient limitation may have different effects on ecosystem structure and function in natural systems. We compared a broad range of 20 ecological processes to determine if these systems have different thresholds where shifts might occur in nutrient limitation. Growth responses indicated N limitation in *Avicennia germinans* (black mangrove) forests in the Indian River Lagoon (IRL), Florida, and P limitation at Twin Cays, Belize. When nutrient deficiency was relieved, *A. germinans* grew out of its stunted form by increasing wood relative to leaf biomass and shoot length relative to lateral growth. At the P-limited site, P enrichment (+P) increased specific leaf area, N resorption, and P uptake, but had no effect on P resorption. At the N-limited site, +N increased both N- and P-resorption, but did not alter biomass allocation. Herbivory was greater at the P-limited site and was unaffected by +P, whereas +N led to increased herbivory at the N-limited site. The responses to nutrient enrichment depended on the ecological process, species, and limiting nutrient and suggested that N- vs. P-limited mangroves do have different thresholds. +P had a greater effect on more ecological processes at Twin Cays than did +N at the IRL, which indicated that the P-limited site was more sensitive to nutrient loading. Because of this sensitivity, eutrophication is more likely to cause a shift in nutrient limitation at P-limited Twin Cays than N-limited IRL.

The ecology of *Batis maritima* in mangrove ecosystems with varying nutrient limitations

D. Whigham

As part of a MSN-funded project in Florida and Belize, we returned to Belize in January 2006 to complete an experiment that had been initiated in 2005. The purpose of the project was to determine if production and growth patterns were limited by different nutrients in Florida and Belize. Previous research had clearly demonstrated that the growth of mangroves in the interior of Twin Cays were phorphorus limited (Feller et al. 2003a) and the same species were nitrogen limited in mangroves near the Smithsonian Marine Station at Fort Pierce (Feller et al. 2003b). No previous research had examined nutrient limitations in understory vegetation at either site. One of the goals of this project was to test the hypothesis that nitrogen limits the growth of *Batis maritima* in Florida and phosphorus in Belize. A second goal was to determine if nutrient limitation influenced the growth form of *Batis* in different habitats. A separate greenhouse experiment at SERC was conducted to examine the effects of both nitrogen, phosphorus and nitrogen + phosphorus on *Batis* growth.

Batis is a clonal species that is common in mangrove forests in mangrove ecosystems in Belize and Florida. *Batis* occurs as an understory plant in sites that are not flooded continuously and are dominated by mangrove trees, both shrub and tree growth forms. *Batis* also occurs in open habitats (i.e., salt pans, cut-over mangrove forest from which all mangroves have been removed, and the edge of shallow lagoons). *Batis*

reproduces by seeds and by clonal propagation. Clonal propagation occurs when parent plants produce one or more types of shoots from which arise new plants. One type of clonal propagation occurs when shoots become tall enough to begin to arch, eventually contacting the ground. Where the shoot contacts the ground, roots are formed and additional shoots are produced. Nodding plants that have rooted can form three types of shoots: vertical, nodding, horizontal. Vertical shoots, as described above, can either remain as vertical shoots or become long enough to become transformed into nodding shoots. In some habitats, horizontal shoots that trail across the surface of the wetland are produced. Horizontal shoots typically emerge at the based of vertical or nodding shoots or they form at the tips of nodding shoots where they contact the ground. Horizontal shoots can produce all three types of shoots.

The study in Belize was conducted on Twin Ceys. In 2005, we selected triplicate sites in two types of habitats in which *Batis* was common. In each site we established three transects with 10 plants selected on each transect. Treatments (phosphorus fertilized and controls) were assigned to plants along each transect with treatments alternated from one plant to the other. Plants were separated by a minimum of two meters. One of our initial goals was to measure annual growth of marked shoots on each plant but that goal was abandoned when it was determined that *Batis* shoots have a high turnover rate, making it impossible to measure shoot growth with once-per-year visits to the study site. We were, however, able to measure the overall growth of individual plants by harvesting above ground biomass after one year. In addition to harvesting biomass, we also recorded the numbers of each shoot type (vertical, nodding, horizontal) produced by each plant. A similar study was conducted in a mangrove-dominated wetland near the Smithsonian's Marine Station at Fort Pierce but the plants were fertilized with nitrogen rather than phosphorus. Due to time and manpower limitations, the Florida study was based only on the responses of plants along one transect in each of two habitat types. At SERC, *Batis* seedlings were used in a greenhouse experiment in which plants were fertilized with nitrogen, phosphorus, and nitrogen + phosphorus.

Harvested plants at both field sites and at SERC were dried at 60°C and weighted. The samples were then prepared for nutrient analysis. Preliminary results of the biomass harvest at both sites are here reported. Some nitrogen analyses have been completed but none of the plants have been analyzed for phosphorus due to budget limitations.

We have not yet started to analyze the growth-form data but the data have been entered into electronic files and QAQC is currently being done.

Plants that were fertilized with phosphorus in Belize produced more than twice as much aboveground biomass as control plants. *Batis* in Florida also responded to fertilization but the response was less pronounced. Results of the greenhouse experiment at SERC clearly shows the importance of both nitrogen and phosphorus as a limiting factor of growth, especially phosphorus . Our preliminary interpretation is that the Belize sites had enough nitrogen in the soils to support additional growth when phosphorus availability was increased. Similar responses have been found for species of mangrove in the same habitats (Feller et al. 2003a). In Florida, there is sufficient phosphorus in the substrate to support *Batis* growth but the application of additional nitrogen had less of an affect on growth. At this time, we are not sure why the response of plants in Florida to fertilization was so small. It may be a result of salt stress as recorded salinities in the areas where the study was conducted have frequently been over 80 ppt, a level that requires halophytes like *Batis* to use much of the available nitrogen to maintain sufficient osmotic values in their cells to continue to be available to maintain an adequate water balance.

Physiological capabilities of "Cand. *Thiobios zoothamnicoli"* the bacterial ectosymbiont of the marine ciliate *Zoothamnium niveum.*

C. Rinke

The giant marine ciliate *Zoothamnium niveum* (Ciliophora, Oligohymenophora) is obligatorily covered by a monolayer of putative chemoautotrophic sulfur-oxidizing (thiotrophic) bacteria. This ectosymbiotic population consists only of one single pleomorphic phylotype named 'Cand. *Thiobios zoothamnicoli*'. The goal of our study was to screen for marker genes encoding key enzymes of the carbon and sulfur metabolism. Therefore, *Z. niveum* colonies were collected on the peat wall of a tidal channel at Twin Cays and at several other mangrove islands on the Belize Barrier Reef. Using polymerase chain reaction (PCR) we found a gene encoding the enzyme ribulose 1,5-bispho-

sphate carboxylase/oxygenase (RuBisCO) which plays a key role in the inorganic carbon metabolism based on the calvin-benson cycle. Furthermore we could detect genes encoding for dissimilatory sulfite reductase and APS reductase, two enzymes which are involved in the sulfur cycle of sulfide-oxidizing bacteria.

Since microbial symbioses with eukaryotic hosts are usually characterized by the physiological capabilities of the symbionts, this study was a crucial step in illuminating the thiotrophic metabolism of 'Cand. *Thiobios zoothamnicoli*'.

Ecology of the *Montastraea* "*annularis*" species complex and long-term changes in coral community composition at two scales on the barrier reef, Carrie Bow Cay, Belize

J. M. Pandolfi

The purpose of this work was to go back to some of the original localities where variation in *Montastraea* "*annularis*" was documented, with a new perspective on species differences to document ecological distribution of each of the three purported species of the *M.* "*annularis*" species complex. First we differentiated the three species morphometrically from 50 samples collected during our first field trip. We then gathered data on the ecological distribution of these species assemblages along 85 20-m transects from 3 sites (Carrie Bow Cay, Tobacco Reef, and Curlew Reef), 6 depths per site (5, 10, 15, 10, 30 m and lagoon) at three sites, using a hierarchical sampling design. Our analysis of the morphometrics data shows clear separation of the three species, and our ecological data show marked environmental differentiation in the distribution of the different species. The project is a collaboration with Dr. Nancy Budd at the University of Iowa.

The University of Queensland has provided a grant for Nancy and me to complete the goals of the CCRE project by finishing a paper on this topic during a UQ-funded research visit to Australia by Nancy in July and August of 2006. The plan for publication is to combine the morphometric data we have for the 50 species collected in FY2001 with the ecological distribution data we collected in FY2003 and FY2004 to produce a definitive documentation of the species complex in Belize. This paper will be integral to any future genetic work to be conducted on the complex from Belize and elsewhere. We will submit the paper to Marine Ecology Progress Series in August 2006, at the end of Nancy's visit to UQ.

The second project is looking at "Long-term changes in coral community composition at two scales on the barrier reef complex, Carrie Bow Cay, Belize". In 2001, I serendipitously located quadrats that had been laid down and photographed in 1986 by Dr. Nancy Budd, from the University of Iowa. These were part of a study where she had emplaced 12 quadrats at 4 different habitats around Carrie Bow Cay, Curlew Cay, and Southwater Cay. Photographs of these quadrats provide unique information for understanding changes on the reef over a 15-year interval. Not only that, but Dr. Budd also has coral abundance data from transects she censused near the quadrats. This provides an opportunity to look at ecological changes on reefs over two scales: the 1-m2 quadrat and the 30-m transect. This is providing us fundamental information, and a very exciting study, on the long-term ecological dynamics of coral reefs over multiple scales, and may help to resolve the paradox of ecological chaos at small spatial and temporal scales versus community predictability at larger ones. I presently have a UQ honours student working on the images obtained in 2002 and 2004 to compare them with those digitized in 2002 by a Smithsonian intern. When all of the photos have been digitized and the corals identified, subsequent analysis will allow us to quantitatively compare coral community dynamics over 15 years at multiple spatial scales. I anticipate submitting a paper on this project in December 2006.

Community dynamics in the central shelf lagoon of the Belizean Barrier Reef

R. B. Aronson & I. G. Macintyre

The highest sea surface temperatures ever recorded, related to both the El Niño Southern Oscillation and global warming, caused severe coral bleaching worldwide in 1997-1998. In Belize, mass bleaching was evident in fore-reef and lagoonal environments during the summer and fall of 1998. Most coral colonies in fore-reef habitats recovered. In contrast, surveys of our permanent study sites at Channel and Cat Cays through March 2001 revealed nearly complete coral mortality. Our quantitative surveys, which were corroborated by qualitative observations throughout the rhomboid shoals of the central shelf lagoon (a 375-km^2 area), showed that this was the first bleaching-induced mass mortality of scleractinian corals observed in the Caribbean.

Populations of the dominant space occupier, *Agaricia tenuifolia*, were almost completely extirpated between October 1998 and January 1999. As of our FY06 survey in January 2006, they have not recovered. At Channel Cay, total coral cover (almost all of which was *Agaricia*) dropped an order of magnitude, from 40% in October 1998 to 4% in March 2001. Resurveys in November 2001 and July 2002 showed that Hurricane Iris (8-9 October 2001) decreased coral cover slightly. There has been a slight increase in total coral cover from 3.6% in July 2002 to 6.2% in January 2006. Coral recruitment at Channel and Cat Cays has been depressed for more than 7 yr following the mass mortality, and Hurricane Iris did not alter that trend.

Persistently high densities of the sea urchin *Echinometra viridis* have kept the cover of fleshy and filamentous macroalgae to low levels, but cover of the encrusting sponge *Chondrilla* cf. *nucula* has been increasing. The cover of *Chondrilla* was 14% at Channel Cay and 9% at Cat Cay in October 1998, rising to 43% and 40%, respectively, in March 2001. Hurricane Iris temporarily depressed the cover of *Chondrilla* at Channel Cay (but not at Cat Cay). By July 2002 sponge cover had returned nearly to pre-storm levels (45%) at Channel Cay, and it was still at that level (47%) in our survey in January 2006.

Further increases in sponge cover will likely prevent the recovery of *A. tenuifolia.* We intend to continue monitoring populations of sessile benthos, coral recruitment and *Echinometra* to track the dynamics of these volatile reef communities in the Belizean lagoon.

Endosymbiont bleaching in the foraminiferan *Sorites dominicensis*

S.L. Richardson

I. Survey of endosymbiont bleaching in Sorites dominicensis

This project represents a continuation of surveys initially conducted in 2005 of endosymbiont-bleaching in epiphytic populations of the dinoflagellate-bearing foraminiferan Sorites dominicensis. Blades of the seagrass Thalassia testudinum were collected from the same two sites surveyed in summer 2005: the shallow reef flat off Carrie Bow; and, Boston Bay, Twin Cays. These two sites differ in depth, water clarity, water movement, and temperature as discussed below. The seagrasses growing on the reef flat off Carrie Bow are often exposed during low tides, while in Boston Bay seagrasses growing in the cen-

ter of the bay remain submerged during low tides. The water on the reef flat off Carrie Bow is clear and shallow (~0.5 m), compared to the somewhat deeper water (~1 m) in Boston Bay, which is stained a reddish-brown color from high concentrations of tannin, leached from the surrounding mangroves.

Thalassia blades were examined under the dissecting microscope, and all attached individuals of *S. dominicensis* were examined for evidence of bleaching, removed from the blades, and stored on a cardboard (paleontological) microslide. The degree of bleaching was noted based on a relative scale: healthy, pale, mottled or bleached (white). Healthy individuals possess a distinct yellowish-brown coloration to their cytoplasm, imparted to the cell by the dinoflagellate endosymbionts. Pale individuals possess a light yellowish-brown coloration to their cytoplasm. In both healthy and pale individuals, cytoplasmic coloration is evenly distributed throughout the test. Bleached individuals have a mottled appearance due to the presence of large patches of light- or white-colored cytoplasm, interspersed with patches of healthy cytoplasm. Individuals were recorded as being totally bleached if they possessed completely white tests. Individuals undergoing reproduction by multiple fission, possessed a central zone of colorless cytoplasm, surrounded by a ring of yellowish-brown cytoplasm in the peripheral chambers of the test where the juveniles begin to form. Tests that were white due to past reproductive events were differentiated from bleached tests, as the reproductive status of the former was evident from the presence of broken or fragmented brood chambers.

A preliminary summary of the results obtained for the 2006 field season are available as a table. Samples collected from Carrie Bow Cay and Twin Cays from 21-23 July show similar patterns of bleaching recorded for the same sites in 2005, whereas a higher incidence of bleaching was observed on the reef flat off Carrie Bow. Samples collected after a major rain storm (27 July & 01 August), exhibited different patterns of bleaching, with the populations in Boston Bay showing a much higher incidence of bleaching than the populations on the reef flat off Carrie Bow. It is hypothesized that this episode of bleaching in the Boston Bay population may have been a result of the influx of freshwater into the bay following the storms.

II. Community ecology of epiphytic foraminiferans in Thalassia *habitats, Twin Cays*

Surveys of the epiphytic foraminiferal communities were conducted on seagrass collected from seven sites located at Twin Cays. Three of the sites were localities that have been sampled in previous studies: Boston Bay, the Dock in the Main Channel, and 'Cuda Cut. The Sponge Haven locality was almost entirely devoid of *Thalassia*, thus no samples were collected from this site. New localities added to the present study include: the entrance to Lair Channel, Twin Bays, West Bay, and the CARICOMP site.

Preliminary analyses of the diversity at each site were made. Species richness (S) ranged from 19-35, with the highest values of S recorded in Twin Bays, and the lowest values recorded in West Bay and at the CARICOMP site. Values of Shannon's *H* ranged from 1.46-2.37, with the highest value of *H* observed in Boston Bay, and the lowest value observed at West Bay. Values of evenness ranged from 0.23-0.43, with the highest value of E calculated for the CARICOMP site, and the lowest values calculated for Twin Bays and the Dock in the Main Channel. The density of epiphytic foraminiferans per cm^2 of seagrass blade ranged from 1.93-4.36, with the highest densities observed in West Bay, and the lowest densities observed in Boston Bay.

A table listing the rank abundances of the most common species recorded at each site is available. The dendritic encrusting species *Rhizonubecula* sp. was observed to be the most common species at most sites except for Boston Bay, where *Sorites dominicensis* was the most common species, and the CARICOMP site, where *Iridia diaphana* was the most common species.

Chemistry influence on feeding preferences of a variety of marine herbivores

A. A. Erickson

Over the past year, three projects have been the focus of my attention, addressing how chemistry influences feeding by marine herbivores. The first two projects examine sea urchin feeding preferences for green algae and how chemistry impacts their selection. This research was a continuation of work that was done in my first year at the Smithsonian Marine Station, Florida. These two studies are important as sea urchins are common and abundant herbivores in a variety of marine habitats, including: coral reef, rocky intertidal, seagrass, and mangrove root environments. While sea urchins feed on various species of algae within differ-

ent phyla, they frequently encounter green algae, which are abundant in coral reef and estuarine environments. Green algae differ greatly in their morphology, structure, and chemistry, and whether or not they are found in habitats that have undergone nutrient enrichment or disturbance. Through feeding, sea urchins can control algal populations. They are capable of removing anywhere between 50-100% of primary production on coral reefs. This has an indirect impact on coral health and survival, given that algae frequently compete for space with or grow as epiphytes on coral. The first project examined feeding by sea urchins on various species of green algae that differ in structure and chemistry. Two main types of defenses that green algae use to deter feeding include terpenes and the dimethylsulfoniopropionate (DMSP) activated defense system. This study was the first to directly compare these two types of defense systems encountered in green algae. The second project examined feeding by a variety of sea urchin species from Florida and Belize on rhizophytic green algae, which are commonly found within coral reef and seagrass habitats. Variation in palatability among rhizophytic greens within the same genus and how differences in algal chemistry influence feeding was explored. This is the first study that directly compares how congeneric chemical extracts influence feeding by sea urchins when offered simultaneously. Finally, I address mechanisms that may be responsible for differences in tolerance to chemical defenses among sea urchin species.

Community dynamics on mangrove roots, and the morphological strategies of mangrove inhabiting sponges

J. Wulff

Community dynamics - At roughly yearly intervals I have completely censused (by drawing maps and measuring volume of every sponge) 10 mangrove roots or root clusters at each of two sites (Hidden Creek and Sponge Haven) 3 times (t = 0, 12, 27 mo), and I hope to re-census once more, in March 07 for a total of 3 years. These data can be directly compared with 3 years of mangrove root sponge census data from Bocas del Toro, Panama, and from the Florida Keys, to better understand the relative importance of abiotic vs. biotic factors, and of the presence or absence of particular species, in dynamics of this apparently space-limited community.

Community assembly - By following settlement, growth, interactions, and mortality on PVC pipes suspended among the mangrove roots in Hidden Creek, I've been tracking the changes in species composition, diversity, cover, etc. over time. The first pipes I suspended were indistinguishable from adjacent mangrove roots by last year, and now subsequently suspended pipes are also covered by the dominant sponge species, chiefly *Tedania ignis*. From pipes suspended at Sponge Haven, it appears that community assembly there is far less deterministic than it is in Hidden Creek. I am now attempting to figure out what causes some pipes at Sponge Haven to remain largely uncolonized even after a few years, while the majority are covered quickly by sponges. In the Pelican Cays, recruitment was so sparse on the first set of pipes suspended that I added a set protected by cages to determine if predators are hampering successful recruitment, and these will be monitored for the first time later this summer.

Morphological strategies of mangrove sponges - Different sponge species play very different roles in the mangrove root community, some of which appear to be predictable by morphology of the sponges. I'm accumulating data on succession and microhabitat occupation of various species in order to compare among sites to see if the roles played by particular species/ morphological types are consistent. At Hidden Creek, I have set up experiments with common sponge species representing a range of morphological types in an attempt to determine how much of the development of observed community structure is due to trade-offs between competitive ability and recruitment rate.

What factors control assortment of sponge species into habitats?

This is a grand reciprocal transplant study, involving dozens of sponge species that are typical of either mangroves, seagrass meadows, or coral reefs. I'm comparing growth and survival of each species in each habitat, hoping to determine what factors really control habitat distribution of these common species. Reciprocal transplants between mangroves and seagrass meadows have been set up, as well as most of the transplants from reef to seagrass and mangroves. Later this summer I will finish setting up the transplants from seagrass and mangroves to the reef. One of the most striking results from the experiments that have already been running for 6 mo to a year is that some of the typical reef and seagrass sponge species tend to grow very

much more rapidly in the mangroves then in their usual habitats.

Beneficial sponge associations in a seagrass meadow - The large sponge *Lissodendoryx colombiensis* inhabits the seagrass meadow at Twin Cays, even though it is readily consumed by the large starfish *Oreaster reticulatus* which is moderately abundant there. The habitat distribution pattern of this sponge species is anomalous because other sponge species that inhabit Caribbean seagrass meadows are rejected by the starfish. By a combination of experimental manipulations, growth rate measurements, and censuses I have been able to demonstrate that 1) *L. colombiensis* gains protection from *O. reticulatus* predation when sponges of other species grow around it, adherent to its surface; and 2) *L. colombiensis* grows rapidly and suffers high levels of mortality when not protected, but 3) survives well when protected by cages in the seagrass meadow. Stable hard substrata on which to live may be limiting in the seagrass meadow, and perhaps this is what the other seagrass sponge species gain from these associations, but this aspect of the study is not yet completed.

Biology of Belizean brittle stars (Echinodermata: Ophiuroidea)

G. Hendler

As they grow, Belizean ophiuroids occupy a succession of different microhabitats: algae, corals, and rubble. The calcareous alga *Halimeda opuntia* provides a vital refuge for the adults of diminutive brooding and asexual species and for the juveniles of large broadcast-spawning species, but broadcast spawning adults live in hard substrate.

To better understand the ecological role of refuge microhabitat for coral reef invertebrates, I am comparing calcareous algae with different growth-forms to assess their relative importance as a substrate for echinoderms. In February 2006, 25 quantitative samples were collected of three species of *Halimeda* (*H. opuntia, H. goreaui,* and *H. copiosa*) from the reef flat rubble zone, the spur and groove zone and the forereef slope, at Carrie Bow Cay. Ophiuroids extracted from the samples have been identified, and their population densities were determined. A preliminary examination of the data suggests that all three species of *Halimeda* serve as refuge habitat for approximately 30 species of ophiuroids, but that the diversity and abundance of brittle stars in *Halimeda* is a combined function of the algal species and its location on the reef. Several species that were particularly abundant 20 years ago are still dominant. As before, the fissiparous species, *Ophiocomella ophiactoides* is found in greatest numbers in the reef flat rubble zone, and the greatest concentration of *Ophiocoma pumila* is in the spur and groove zone. However, maximum densities of *Ophioderma rubicundum* and *Ophiothrix angulata* have shifted from the spur and groove zone to the forereef. Thus, the distribution and abundance of dominant species in different reef zones appears to be changing over time.

Mangrove removal in the Belize cays: Effects on mangrove-associated fish assemblages intertidal and subtidal

D.S.Taylor, E.A. Reyier, W.P. Davis & C.C. McIvor

We investigated the effects of mangrove cutting on fish assemblages in Twin Cays, Belize, in two habitat types. We conducted visual censuses at two sites in adjoining undisturbed/disturbed (30%–70% of shoreline fringe removed) sub-tidal fringing Rhizophora mangle Linnaeus, 1753. Observers recorded significantly more species and individuals in undisturbed sites, especially among smaller, schooling species (e.g., atherinids, clupeids), where densities were up to 200 times greater in undis¬turbed habitat. Multivariate analyses showed distinct species assemblages between habitats at both sites. In addition, extensive trapping with wire minnow traps with¬in the intertidal zone in both undisturbed and disturbed fringing and transition (landward) mangrove forests was conducted. Catch rates were low: 638 individuals from 24 species over 563 trap-nights. Trap data, however, indicated that mangrove disturbance had minimal effect on species composition in either forest type (fringe/transition). Different results from the two methods (and habitat types) may be ex¬plained by two factors: (1) a larger and more detectable species pool in the subtidal habitat, with visual “access” to all species, and (2) the selective nature of trapping. Our data indicate that even partial clearing of shoreline and more landward man¬groves can have a significant impact on local fish assemblages.

Selective predation by parrotfishes on the reef coral *Porites astreoides*

R.D. Rotjan & S.M. Lewis

Direct predation by parrotfishes (Scaridae) may be an important stressor and mortality agent for reef-building corals, yet the patterns and consequences of such predation have received little attention. In a Belizean back reef habitat, we found that parrotfish predation causes mortality of the common reef-building coral, *Porites astreoides*, with >13 % of *P. astreoides* colonies showing partial or total colony mortality. Predation was not uniformly distributed, as completely intact colonies occurred adjacent to heavily grazed colonies exhibiting >50% tissue lost to parrotfish predation. We examined whether differential predation on *P. astreoides* colonies might reflect differences in either coral nutritional quality or in coral-associated macroborers. Nutritional quality of coral tissue, measured as C:N ratios, did not differ significantly between grazed and intact *P. astreoides* colonies. However, significantly higher densities of coral-associated macroborers (which included barnacles, polychaetes, and vermetid molluscs) were found in grazed portions compared to ungrazed portions of the same P. astreoides colony. Thus, one explanation for selective grazing on *P. astreoides* colonies is that parrotfishes may be targeting coral areas with higher densities of macroboring organisms. Comparison of C:N ratios among possible dietary components suggests that macroborer consumption could potentially provide nutritional benefits to mainly herbivorous parrotfishes.

These results corroborate a growing body of evidence indicating that parrotfish predation is an important source of coral mortality, and provide a novel explanation for selective coral predation by parrotfish.

Vacancy chains and shell use in *Coenobita clypeatus* hermit crabs: Finding a dream home on a small tropical island

S.M. Lewis & R.D. Rotjan

Vacancy chains theory describes a unique mechanism for the distribution of animal resources applicable to any resources that are discrete, reusable, and limited to use by single individual/ group at a time. In hermit crabs, a single vacant shell can start a sequentia l chain of shell switches that provides new resources to many individuals. Using the terrestrial hermit crab *Coenobita clypeatus*, we examined the hypothesis that this process will cause trickle-down improvements in shell quality for vacancy chain participants. In a field experiment, we added new shells to an island population of *C. clypeatus* hermit crabs and six months later found that average shell fit had improved for crabs of all sizes, possibly from propagation of benefits through vacancy chains. In laboratory experiments, on average 3.2 crabs switched shells following the addition of a single vacant shell, and the majority of these crabs measurably improved their shell fit. Experimental vacancy chains were always terminated when a crab discarded a damaged shell. Finally, hermit crabs in damaged shells were more successful when competing for a new, high quality shell than hermit crabs with poor shell fit. Taken together, these finding suggest that vacancy chains play an key role in hermit crab resource use and behavioral interactions. We also present a conceptual model differentiating between synchronous and asynchronous vacancy chains, and discuss the ecological and behavioral costs and benefits associated with each type. These results may contribute to understanding resource acquisition behavior and resource use in a wide range of organisms.

Dolphin foraging

O. Oftedal

The purpose of the trip was to survey facilities and examine the logistics of including the Carrie Bow site in our research on dolphin foraging. To determine the feasibility of including this location as a study site, I interviewed several people, including local fishermen, who affirmed that dolphins are regularly sighted in the area. I also spoke to local fishermen about availability of trapped fish and was told that it could be arranged if some advance notice were given. In particular, a gentleman by the name of Junior, who often works for Pelican Beach Resort, offered to make arrangements for us. The Twin Cayes site where long-term ecological monitoring has been going on was also examined, and a fisherman was located who was trapping fish nearby and who would be willing to trap fish for us. There were reports of nearby dolphin sightings during myvisit, and in addition to the collection of dolphin prey we hope to use Carrie Bow as a base of operations for dolphin biopsy samples. The goal is to determine stable isotope and fatty acid signatures in potential prey items and to match these with those apparent in dolphin tissue. We currently have a permit application for dolphin biopsy work at several locations in Belize (including Carrie Bow) under review by the Belize Department of Fisheries.

Species Interaction and Behavior

The biology of *Pseudovorticella paracratera* Ji et al., 2004: A ciliate/bacteria symbiosis on mangrove peat

J. A. Ott & R. Ott

Colonization experiments

Holes with a diameter of 5 mm were drilled into 60 Falcon tubes with a volume of 15ml. Two holes were 20 mm from the upper rim on opposing sides of the plastic tube, two more 45 mm from the rim. The tubes were pushed into the mangrove peat in 6 groups of 10 until flush with the peat surface and left for various periods of time. One tube of each group was retrieved after 2, 4, 6, 8, 10, 12 and 14 days and examined under a dissecting microscope.

Colonization was very variable, both between replicas and sampling dates. First settlement of both *Pseudovorticella paracratera* and *Zoothamnium niveum* was observed on day 6. Contrary to expectations initial settlement was *P. paracratera* dominated, which however, occurred in only one of the tubes. On days 8 and 10 *Z. niveum* colonies of various sizes were found and *P. paracratera* was absent. On day 12 the highest number of *Z. niveum* colonies was found together with several *P. paracratera* (again all of them in one tube). On day 14 no ciliates were found and the experiment was terminated. A second series of experiment which was started to repeat the first phase again showed a high number of *P. paracratera* in one tube after 5 days together with a low number of *Z. niveum* distributed over several tubes.

These results falsify the hypothesis, that *Pseudovorticella paracratera* is a late settler which colonizes after *Zoothamnium niveum* when sulfide flux decreases. An explanation of the observed pattern could be found in the different life history of the two ciliates – colonies of *Z. niveum* arise by settlement of swarmers and groups of young colonies are the result of multiple colonization events from swarmers arriving from elsewhere. Only after about 4 days swarmers are produced which could settle next to their parent colony and thus increase colony number. In contrast, *P. paracratera* multiplies quickly after settlement (see cultivation) and one successful swarmer may give rise to a group of zooids within a few days. The results suggest that both *Z. niveum* and *P. paracratera* colonize fresh sulphide sources. The probably more long lived and far

ranging swarmers of *Z. niveum* are the more reliable colonizers, whereas the less frequent colonization by *P. paracratera* leads to the establishment of groups with many individuals produced on the spot. The observed correlation in the field that groups of mature or senescent *Z. niveum* are more likely to be associated with *P. paracratera* can be understood considering the greater age of such groups which increases the chance of a settlement by *P. paracratera*

Cultivation

After a number of trials cultivation of *Pseudovorticella paracratera* was successful by placing a piece of peat containing *P. paracratera* individuals in dishes with seawater and adding a bean, which had been soaked in seawater for at least 2 days. Sulfur bacteria developed on the surface of the bean and although the bean itself was not colonized, the bacteria coating *P. paracratera* remained white and the ciliates multiplied, probably sustained by the sulphide produced by decomposition of the bean. This set-up, however, did not allow precise counts of the new *P. paracratera* individuals produced. Estimates however point to a doubling time of between 12 to 18 hours.

Identification

Using the preserved and live material W. Foissner (University of Salzburg) tentatively identified the ciliate as *Pseudovorticella paracratera* Ji et al. 2004, who described the species from marine waters in China without, however, mentioning the symbiotic bacteria. A molecular characterization of both bacteria and ciliates using the rRNA gene is under way.

Is coral recruitment controlled by coralline algae facilitator species? If so: What facilitates the facilitators?

Part 1. Recruitment, experimental procedures

V. Paul, R. Ritson-Williams, S. Arnold & R. Steneck

Our goal was to test the settlement preferences of larvae from various species of broadcast spawning corals for different species of crustose coralline algae (CCA). We had hoped to collect larvae from both *Acropora cervicornis* and *A. palmata* to compare these two species, however, *A. cervicornis* colonies near Carrie Bow Cay did not spawn during August, 2006, and only a few colonies of *A. palmata* spawned. Egg and sperm bundles were collected from four individual *A. palmata* colonies in the field on the night of Aug. 12, 2006. Eggs and sperm from all four colonies were allowed to mix naturally in a beaker, and eggs were successfully fertilized. Larvae were reared for five days before being used in settlement assays. Twelve different treatments were offered separately in well plates (10 *A. palmata* larvae per well) and larval metamorphosis was recorded after 12 and 24 hours. The different treatments tested included filtered seawater, clean coral rock, and the algae *Amphiroa* sp, *Hydrolithon boergesenii*, *Lithoporella atlantica, Neogoniolithon affine, N. mamilare, N. munitum, Paragoniolithon solubile, Peysonellia* sp., *Porolithon pachydermum*, and *Titanoderma prototypum*. Larvae settled and metamorphosed on only a few species of CCA (*Hydrolithon boergesenii, Lithoporella atlantica, Neogoniolithon affine,* and *Titanoderma pro-*

totypum) and did not settle in high numbers in filtered seawater or on clean coral rock. In a few cases, larvae also metamorphosed in high numbers in the plastic wells in response to the *Lithoporella atlantica, Paragoniolithon solubile,* and *Porolithon pachydermum*, possibly suggesting the presence of water soluble cues emanating from these species of CCA.

In two separate experiments *A. palmata* larvae were offered choices between two species of CCA in small petri dishes (20 larvae per dish). In one experiment larvae preferred to metamorphose on *Titanoderma prototypum* over *Paragoniolithon solubile*, and in the other experiment larvae clearly chose *Hydrolithon boergesenii* over *P. solubile*. These studies show that *A. palmata* larvae can select preferred substrate for settlement and metamorphosis.

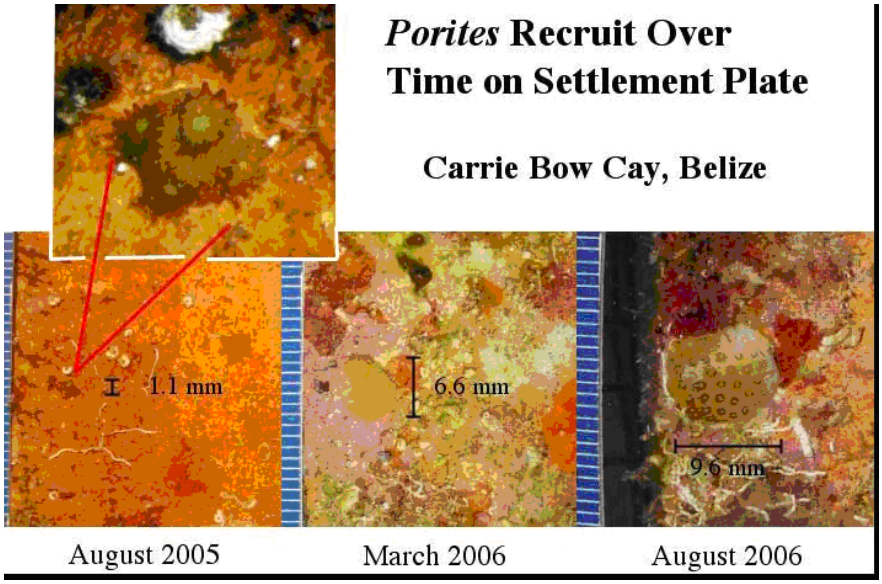
Similar preference experiments were also conducted with *Montastraea faveolata* larvae. *Montastraea faveolata* spawned in buckets on the night of August 16, 2006. Egg and sperm bundles were collected from several colonies and mixed together in a beaker to fertilize the eggs. Six-day old larvae were offered different treatments in well plates (20 larvae per well) including all of the same CCA species that were offered to *A. palmata* larvae.

The results contrasted those for the *A. palmata* larvae because very few species of CCA promoted metamorphosis of *M. faveolata*. Larvae generally settled on the rock surrounding the CCA, and only settled on *Neogoniolithon affine* and *Titanoderma prototypum* as much as or more than on rock. In choice assays with two species of CCA offered simultaneously, larvae most often settled on rock, and only *Titanoderma prototypum* induced metamorphosis on its surface.

Part 2. Recruitment, in situ monitoring

R. Steneck, S. Arnold, V. Paul & W. Adey

The monitoring of coral settlement plates is being carried out by Robert Steneck and Suzanne Arnold. In June 2005, a total of 250 terracotta coral settlement plates were affixed to the fore-reef adjacent Carrie Bow and South Water Cays. Fifty plates were placed at each of the four 10 m sites. One 5 m site was selected where



50 plates were attached, half of which were covered with 1/4" wire mesh cages to mimic the effects of algal overgrowth.

The following August, at each site, transects were completed to quantify the abundance of live coral as an estimate of coral larval availability, densities of juvenile corals (those less than 40 mm in diameter) were surveyed, and fish census and bite rate measures were completed to quantify the trophic structure of each reef. All settlement plates, top and bottom, were photographed underwater to quantify succession after two months. Additionally, half of the plates were analyzed under the microscope for newly settled corals and abundance of facilitator species. As expected, very little fouling was found to have occurred during the short time since deployment (67 days), and only five newly settled coral were found at the 10m depth. Mean juvenile coral density at 10 m was 4.96 ± 1.02 juveniles per m2, a low density compared to surveys from Glovers Reef, Callabash Cay, and Bonaire (Netherlands Antilles). Species composition of the juveniles surveyed was 26.5% *Siderastrea radians*, 26.5% *Agaricia* spp.,

20.6% *Porites astreoides*, 17.6% *Siderastrea siderea*, 2.9% *Porites porites*, 2.9% *Dichocoenia stokesii*, and 2.9% *Acropora palmata*.

In March 2006, 271 days after deployment of the settlement plates, the same subset of plates were analyzed. Seventy-three new coral settlers were found, and mortality of the 5 old recruits at 10m was 40%. The plates were monitored again in August 2006 and 91 new settlers were found, bringing the total number of spat up to 169 (1.69 spat/plate) over the course of the 427-day study period. All recruits were of the genera *Porites* and *Agaricia*, and notably, *Titanoderma prototypum* was observed on the undersides of several plates, but in very low abundance. Spat settled primarily on crustose coralline alga (CCA) species of greater abundance. Thirty-one percent of spat settled on CCA, 29.2% settled on polychaete worm tubes, 29.2% settled on bare terracotta, 6% settled on *Peyssonnelia* spp., 3% settled on invertebrate crusts, and 1.2% settled specifically on *T. prototypum*.

Post-settlement mortality of the original August 2005 cohort increased to 80%, and post-settlement mortality of the March 2006 cohort was observed to be 73% after 156 days since discovery. Thus, as seen in Bonaire, Netherlands Antilles, as time passes after space is opened up, chances of survival for a newly settled coral decline, or this window of time for successful recruitment closes. Compared to other regions in the Caribbean, Carrie Bow Cay has relatively high rates of coral settlement but relatively low densities of juvenile corals. This pattern suggests higher incidences of post settlement mortality than seen in other regions of the Caribbean. It is the environmental conditions that cause such a pattern that we hope to investigate further.

Microbial associates with early life stages of scleractinian corals

K. Sharp

Coral animals consist of complex multi-species associations, harboring diverse organisms in their tissues, including zooplankton, archaea, bacteria, diatoms, and zooxanthellae. Recent research indicates that in some coral species, bacteria and archaea have evolved to be in persistent, specific associations with coral hosts, but these have yet to be identified in most coral species. The extent to which these associations are specific, and the mechanisms for their maintenance in the environment are not yet known. As a Marine Science Network Post-Doctoral Fellow, my main research objective is to understand the specificity and diversity of microbial communities found in scleractinian corals throughout the Caribbean. Instead of investigating the highly complex and dynamic bacterial and archaeal communities found in the adult colonies, my research focuses on the early life stages – gametes, larvae, and juvenile polyps.

In August, during a spawning event, the corals *Montastraea faveolata* and *Acropora palmata* released gamete bundles. Gamete bundles were harvested, fer-

tilized, and swimming planula larvae were fixed for future labwork at various timepoints over the course of development until settlement (6days). In addition, larvae were settled on glass microscope slides and maintained in flowing seawater for an additional 16-20 days until we returned for next month's spawning trip. In September, *M. franksi, M. faveolata*, and *M. annularis* spawned. Gametes and larvae were prepared for future molecular and fluorescence microscopy applications, and the juvenile *M. faveolata* and *A. palmata* polyps from the August collection were fixed once zooxanthellae acquisition was visibly detected.

Recent labwork, including fluorescence in situ hybridization (FISH) and PCR, indicates the absence of any bacterial or archaeal cells on gametes and larvae from all collected coral species, in addition to *A. palmata* collected in the 2005 field season (V. Paul and R. Ritson-Williams). Future work includes exploring the possibility of acquistion of bacteria by the juvenile polyps.

Investigation of transmission of microbes in gametes and larvae in two Caribbean coral genera (*Montastraea* and *Porites*)

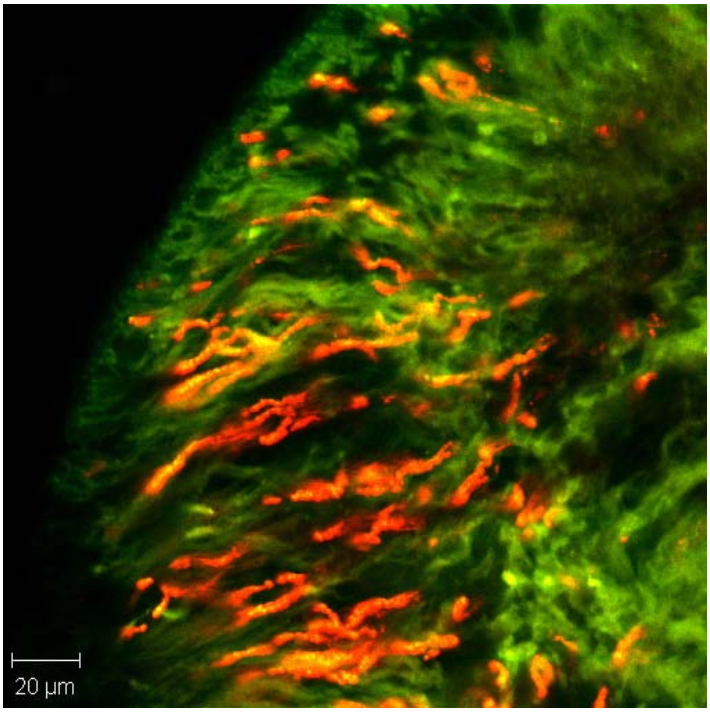
K. Sharp

During the funding period in 2006 (February-present), I have been studying microbes associated with gametes and larvae of various Caribbean corals. In my initial proposal, I identified the primary goals of the project to be 1)identifying symbiotic bacteria or archaea that are persistently associated with the corals, and therefore likely to be significant to coral ecology, and 2) understanding the specificity of these associations, their persistence across geographical and temporal barriers, and their transmission in the environment. The underlying hypothesis and main questions of this project can be outlined as below:

Specific symbiotic associations exist between corals and microbes, and these specific associations are maintained in the environment via vertical transmission (through reproductive tissues) of the microbes.

Is there a difference in vertical transmission between brooding corals and spawning corals?

If there are bacteria and/or archaea that are vertically transmitted in corals, do they engage in long-term, specific association with coral hosts? Are they always present in all populations across the Caribbean?



Question 1: Is there a difference in vertical transmission between brooding corals and spawning corals?

In order to compare brooding corals with spawning corals, gamete bundles were collected from the broadcast spawning corals *Acropora cervicornis, A. palmata, Montastraea annularis, M. faveolata,* and *M. franksi* from both Panama and Belize. Larvae from brooders (*Porites astreoides* and *Favia fragum*) were collected from the Florida Keys.

Egg-sperm bundles and larvae were collected from *A. cervicornis, A. palmata, M. faveolata, M. annularis,* and *M. franksi* from Belize and Panama in 2005 and Belize in 2006. In all samples, FISH with general eubacterial and archaeal probes suggests the absence of microbes from egg-sperm bundles, from eggs that sat for hours in still water (bucket collection), and from larvae up to 6 days old.

Larvae were successfully harvested from *P. astreoides* and *F. fragum* colonies collected in the Florida Keys in May-June 2006 at Mote Marine's Marine Tropical Laboratory (Summerland Key, FL). These larvae were fixed in timepoints ranging from directly after release through to day 6, just prior to settlement. In contrast to the gamete bundles and larvae of the spawning corals, fluorescently labeled general eubacterial and archaeal probes in fluorescent in situ hybridization (FISH) show the presence of bacteria (but absence of archaea) in the larvae of *P. astreoides* and *F. fragum.* Figure 1 shows general eubacterial probes hybridizing

with bacterial cells associated with the cilia on the aboral pole in *P. astreoides* larvae. In Figure 2, bacterial cells are shown in between the epithelial cells of the gastric cavity in *F. fragum* planulae. These bacteria are present immediately after release from adult colonies, and they remain in the larvae through the 5-day swimming period. Bacteria were observed on the cilia and in the gastric cavities of both brooding species.

How do different coral reef herbivores respond to chemical defenses of coral reef macroalgae and cyanobacteria?

V. Paul, R. Ritson-Williams, A. Capper, M. Becerro & C. Ross

The goal of this year's study was to experimentally examine the chemical basis for prior observations of the low susceptibility of different species and forms of the brown algae *Dictyota* spp., *Lobophora variegata* and *Stypopodium zonale* and the cyanobacteria *Lyngbya* spp. and *Symploca* spp. to consumption by coral reef herbivores. We tested chemical extracts from these macroalgae and cyanobacteria incorporated into artificial foods to see how natural products from these algae influence the feeding behavior of different reef herbivores including reef fishes and the sea urchin *Diadema antillarum.* We hypothesized that chemical defenses explain the patterns in palatability we observed. Field assays with natural assemblages of reef fishes and aquarium assays with *Diadema antillarum* showed that some but not all species of *Lyngbya* and *Symploca* were chemically defended against both types of herbivores. In contrast, *Lobophora variegata* and some species of *Dictyota* were not well defended chemically. Isolation of the compounds responsible for the chemical defense of *Stypopodium zonale* and *Taonia abbottiana* was initiated by testing fractions of the extracts against reef fishes in the field and identifying some fractions that contain deterrent compounds.

Geographical differences in chemistry and palatability to grazers

A. Capper

The palatability of non-polar and polar extracts from *Lyngbya majuscula* (IRL2 from the Indian River Lagoon), *L. polychroa* (Fort Lauderdale) and *Oscillatoria* spp. blooms were tested against a range of macrograzers and mesograzers in Belize at Carrie Bow Cay. Treatment foods were prepared using cyanobacterial extracts (non-polar extracted in 1:1 ethyl acetate: methanol, polar extracted in 1:1 ethanol:distilled water) which were coated onto powdered *Gracilaria tikvahaei* (a palatable alga that contains no major secondary metabolites) using ethyl acetate and methanol. Solvents were removed by rotary evaporation. Control food consisting of *G. tikvahaei* coated with solvents (ethyl acetate and methanol) was also prepared prior to departure. No significant difference was observed between *L. majuscula* (IRL2) non-polar, polar and control foods for the sea urchin, *Diadema antillarum* (Friedmans p=0.285, n=8). Majid crabs showed a slight preference for non-polar *Oscillatoria* spp. (p=0.05, n=19) although post-hoc analysis showed no distinction between non-polar and polar extracts. Green crabs (spp. to be verified) showed no preference amongst extract coated and control food (Friedmans p=0.172, n=10). *Lyngbya polychroa* collected from Fort Lauderdale blooms and extracted prior to the trip at SMSFP did not appear to be a feeding deterrent to majid crabs (Friedmans, p=0.230, n=8)

or fish (Friedmans p=0.348, n=20), but both non-polar and polar extracts did deter *D. antillarum* (Friedmans, p<0.001, n=13). *Lyngbya polychroa* collected from Twin Cays in 2005 however, was not deterrent to *D. antillarum* (Friedmans, p=0.491, n=10), suggesting that the chemistry of *L. polychroa* may vary geographically. This data will help provide a detailed account of the palatability of *Lyngbya* spp. to sympatric and non-sympatric grazers.

Two species of *Lyngbya* were collected in Belize from Twin Cays (spp. to be verified, possibly red and green morphs of the same species). These have been brought back to SMSFP and can be extracted to assess palatability of extracts to local herbivorous meso- and macrograzers.

A wide range of palatability feeding preference assays were also carried out with Raphael Ritson-Williams and Cliff Ross using a number of algal and cyanobacteria species including *Lobophora, Symploca, Taonia* and *Stypopodium*. Other *Lyngbya* spp. previously collected in Belize in 2004 and 2005 were tested against *D. antillarum*. Both Reef Flat *Lyngbya* (Friedmans, p=0.529, n=10) and *Lyngbya* spp. 1, 2005 (Friedmans, p=0.120, n=9) did not deter feeding. However, *Lyngbya* spp. 1 non-polar and polar extracts were both deterrent to reef fish (Friedmans, p<0.001, n=20), whilst only the non-polar extracts of *Lyngbya* spp. red, 2004, were deterrent (Friedmans, p=0.008, n=18).

It is suggested that further trials be carried out using Belizean and Floridian *L. polychroa* and *L. majuscula* to ascertain geographical differences in chemistry and palatability to grazers. Further fractionation of *L. polychroa* has yielded microcolin-A which could be tested against a range of grazers to ascertain any feeding deterrent capabilities. *Lyngbya majuscula* from both locations requires further extraction and fractionation.

Processes across Ecosystems

The effects of biogeographic variation in recruitment on the ability of species to invade coastal marine ecosystems

R. Osman, G. Ruiz, A. Hines & R. Whitlatch

The mode by which species successfully invade new habitats is a pressing ecological research issue (e.g. Rejmanek and Richardson 1996, Williamson and Fitter 1996, Moyle and Light 1996). Invasions can directly or indirectly alter local community composition (e.g., Nichols et al. 1990, Carlton and Geller 1993, Travis 1993), modify ecosystem dynamics (e.g. Manchester and Bullock 2000), and change biodiversity (e.g., Naeem et al. 1994, Tilman and Downing 1994). Understanding the invasion process is critical not only in determining the consequences of the inadvertent introduction of new, exotic species into existing communities (Kareiva 1996) but also in delineating the mechanisms by which any species might expand into new habitats or new areas of a region and the resultant community and ecosystem changes.

Sessile invertebrate or fouling communities are excellent systems in which to examine rigorously both the life-history attributes that characterize successful invaders as well as those attributes of native communities that govern their susceptibility to invasion. Fouling communities occur in all coastal habitats and can be found in all biogeographic regions. These communities contain species with a variety of lifehistories, yet their principal species are usually permanently attached as adults and are easy to manipulate. Although the species within these communities differ among regions, they function in similar ways. Most have planktonic larvae as the main means of dispersal, feed from the water column, compete for limited available space, and are preyed on by a variety of mobile vertebrate and invertebrate predators. Because fouling species are sessile and relatively small in size, natural communities can develop on small, discrete substrates with larval dispersal and recruitment linking communities within a site or habitat as well as within a region. These attributes make them ideal systems that can be experimentally manipulated in the field to test directly hypothetical relationships while maintaining natural levels of abundance, species composition, and diversity.

Among fouling communities, a major difference is the number of available species that have some reasonable probability of recruiting to a particular site within a region. For example, Osman and Dean (1987) compared studies conducted in several regions and found that the pools of species varied by almost an order of magnitude. Estimates based on the cumulative number of species found in each study followed a similar pattern as well as the maximum total number of species found at sites sampled within each region. However, both the mean number of species found on individual substrates and the correlated richness at each site (a subset of the regional species pool) varied

greatly among the study sites within each region. These patterns potentially result from 1) the low probability of recruits of many species in the regional species pool actually reaching a particular site during the course of investigation and 2) the high probability of local, within-site dispersal of species already present at a particular site. Alternatively, high predation and local extinction rates at some sites may prevent certain species in the regional species pool from colonizing these sites (e.g. Osman and Whitlatch 1996, 1998, 2004).

In addition, there appear to be intra- and inter-regional recruitment and colonization patterns that correlate with diversity. For example, when we contrast regions, recruitment rates tend to be lower in regions of higher diversity. However, as Levine (2000) found for a riparian system, recruitment rates at sites or habitats within regions often increase with increasing local species richness. Also, the rates of community development and space occupancy seem to mirror recruitment patterns. In southern California, substrates often require >6 months for space to become fully occupied while in New England this usually occurs in 1-2 months. In low diversity sites (e.g. < 10 species) in Chesapeake Bay we have observed similar declines in open space in periods of 2-4 wk. These relationships suggest that processes, such as recruitment and growth, can co-vary among species on both local, regional, and inter-regional scales. The goal of our research is to use the links between local and regional patterns to determine the underlying mechanisms that control the fouling communities' susceptibility to invasion. In southern New England we found that increasing diversity on a substrate imparted resistance to invasion because in more diverse communities there was a greater potential for newly-opened space to be re-occupied by one or more of the native species present (Stachowicz et al. 1999, 2002). However, patterns of lower recruitment rates, lower colonization rates, and possibly lower growth rates in regions of higher diversity suggest that these regions may be invaded more easily because more space remains open for longer periods of time.

We contend that the basis of these patterns is the availability of a critical resource, space, and how it is affected by spatial and temporal variations in the rates of recruitment, growth, and mortality of all species. It is the variation in these processes that we see as affecting observed diversity patterns as well as the potential for communities to be invaded. Therefore, the long-term goals of our research are determining 1) how the availability of a key resource, space, influences regional and local variation in recruitment, growth, and mortality rates of native species and their diversity, 2) how these communities may constrain the success of invaders through their influence on resource availability, and 3) if and how invading species differ from natives in their abilities to capture this critical resource.

Herbivore responses to nutrient enrichment and landscape heterogeneity in the mangrove ecosystem

I. Feller & A. Chamberlain

Complex gradients in forest structure across the landscape of offshore mangrove islands in Belize are associated with nutrient deficiency and flooding. While nutrient availability can affect many ecological processes, here we investigate how enrichment with nitrogen (N) and phosphorus (P) interact with forest structure in three distinct zones (fringe, transition, dwarf) to alter patterns of herbivory as a function of folivory, loss of yield, and tissue mining. The effects of nutrient addition and zone varied by functional feeding group or specific herbivore. Folivory ranged from 0-0.4% leaf area damaged per mo, but rates did not vary by either nutrient enrichment or zone. Leaf lifetime damage ranged from 3-10% of the total leaf area and was caused primarily by the omnivorous tree crab *Aratus pisonii*. We detected two distinct spatial scales of response by *A. pisonii* that were unrelated to nutrient treatment, i.e., most feeding damage occurred in the fringe zone and crabs fed primarily on the oldest leaves in the canopy. Loss of yield caused by the bud moth *Ecdytolopha* sp. varied by zone but not by nutrient treatment. A periderm-mining *Marmara* sp. responded positively to nutrient enrichment and closely mirrored the growth response by *Rhizophora mangle* across the tree-height gradient. In contrast, a leaf-mining *Marmara* sp. was controlled by parasitoids and predators that killed >89% of its larvae. Thus, nutrient availability altered patterns of herbivory of some but not all mangrove herbivores. These finding support the hypothesis that landscape heterogeneity of the biotic and abiotic environment has species-specific effects on community structure and trophic interactions. Predicting how herbivores respond to nutrient over-enrichment in mangrove ecosystems also requires an assessment of habitat heterogeneity coupled with feeding strategies and species-specific behavior measured on multiple scales of response.

Variation in hydraulic conductivity of mangroves: Influence of species, salinity, and nitrogen and phosphorus availability

C. E. Lovelock, M. C. Ball, I. C. Feller, B. M. J. Engelbrecht & S.M.L. Ewe

We investigated how species identity and variation in salinity and nutrient availability influence the hydraulic conductivity of mangroves. Using a fertilization study of two species in Florida, we found that stem hydraulic conductivity expressed on a leaf area basis (Kleaf) was significantly different among species of differing salinity tolerance, but was not significantly altered by enrichment with limiting nutrients. Reviewing data from two additional sites (Panama and Belize), we found an overall pattern of declining leafspecific hydraulic conductivity (Kleaf) with increasing salinity. Over three sites, a general pattern emerges, indicating that native stem hydraulic conductivity (Kh) and Kleaf are less sensitive to nitrogen (N) fertilization when N limits growth, but more sensitive to phosphorus (P) fertilization when P limits growth. Processes leading to growth enhancement with N fertilization are probably associated with changes in allocation to leaf area and photosynthetic processes, whereas water uptake and transport processes could be more limiting when P limits growth. These findings suggest that whereas salinity and species identity place broad bounds on hydraulic conductivity, the effects of nutrient availability modulate hydraulic conductivity and growth in complex ways.

Linking physiological processes with mangrove forest structure: Phosphorus deficiency limits canopy development, hydraulic conductivity and photosynthetic carbon gain in dwarf *Rhizophora mangle*

C. E. Lovelock, M. C. Ball, B. Choat, B. M. J. Engelbrecht, N. M. Holbrook & I. C. Feller

Spatial gradients in mangrove tree height in barrier islands of Belize are associated with nutrient deficiency and sustained flooding in the absence of a salinity gradient. While nutrient deficiency is likely to affect many parameters, here we show that addition of phosphorus (P) to dwarf mangroves stimulated increases in diameters of xylem vessels, area of conductive xylem tissue and leaf area index (LAI) of the canopy. These changes in structure were consistent with related changes in function, as addition of P also increased hydraulic conductivity (Ks), stomatal conductance and photosynthetic assimilation rates to the same levels measured in taller trees fringing the seaward margin of the mangrove. Increased xylem vessel size and corresponding enhancements in stem hydraulic conductivity in P fertilized dwarf trees came at the cost of enhanced midday loss of hydraulic conductivity and was associated with decreased assimilation rates in the afternoon. Analysis of trait plasticity identifies hydraulic properties of trees as more plastic than those of leaf structural and physiological characteristics, implying that hydraulic properties are key in controlling growth in mangroves. Alleviation of P deficiency, which released trees from hydraulic limitations, reduced the structural and functional distinctions between dwarf and taller fringing tree forms of *Rhizophora mangle*.

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Participants 2005-06

* Served as station manager
** Steering Committee Member

Adey, Walter, Smithsonian Institution, Department of Botany, Washington, DC 20013-7012
Arnold, Susie, University of Maine School of Marine Sciences, Darling Marine Center, Walpole, ME 05473
Aronson, Richard, Dauphin Island Sea Lab, 101 Bienville Boulevard, Dauphin Island, Alabama 36528.
Baldwin, Carole**, Smithsonian Institution, Department of Vertebrate Zoology, Washington, D.C. 20560-0159
Ball, M. C., Smithsonian Environmental Research Center, P.O. Box 28 Edgewater, MD 21037
Becerro, Mikel, Smithsonian Marine Station at Fort Pierce, Fort Pierce, FL 34949
Brook, Barrett, Smithsonian Institution, National Museum of Natural History, Department of Botany, Washington, D.C. 20560-0166
Capper, Angela, Postdoctoral Fellow, Smithsonian Marine Station at Fort Pierce, Fort Pierce, FL 34949
Carpenter, Mike*, Smithsonian Institution, National Museum of Natural History, CCRE Program, Washington D.C., 20560-0163
Chamberlain, Anne, Smithsonian Environmental Research Center, Edgewater, MD 21037
Cheeseman, John, Department of Plant Biology, University of Illinois, 505 S. Goodwin Ave., Urbana, IL, 61801
Chinain, Mireille, Institut Territorial de Recherches Médicales Louis Malardé, BP 30 Papeete, Tahiti, French Polynesia
Choat, Brendan, Organismic and Evolutionary Biology, Harvard University, Cambridge, Massachusetts, 02138
Cole, Kassi, Department of Biology, University of Southwestern Louisiana, P.O. Box 42451, Lafayette, LA, 70504-2451
Chróst, Ryszard J., Microbial Ecology Department, University of Warsaw, U1. Karowa 18, PL-00-927 Warsaw, Poland
Driskell, Amy, Laboratory of Molecular Systematics, National Museum of natural History, Smithsonian Institution, Washington, D.C.
Engelbrecht, Bettina M. J., Smithsonian Tropical Research Institute, P.O. Box 2072, Balboa, Panama
Erickson, Amy, Smithsonian Marine Station at Fort Pierce, Fort Pierce, FL 34949
Ewe, Sharon Mei Ling, Postdoctoral Fellow at Fort Pierce Marine Station, Smithsonian Institution
Fauchald, Kristian, Smithsonian Institution, National Museum of Natural History, Department of Invertebrate Zoology, Washington, D.C. 20560-0163
Faust, Maria, Smithsonian Institution, National Museum of Natural History, Department of Systematic Biology (Botany), Washington, D.C. 20560
Felder, Daryl, Department of Biology, PO Box 42451, Lafayette, LA 70504-2451
Feller, Candy**, Smithsonian Environmental Research Center, P.O. Box 28 Edgewater, MD 21037
Fredericq, Suzanne, University of SW Louisiana Dept. Biology, Lafayette LA 70504-2451

Ferraris, Joan**, National Institutes of Health, Building 10, Room 6N307, Bethesda, MD 20892

Gambi, Maria Cristina, Stazione Zoologica «Anton Dohrn», Laboratorio di Ecologia del Benthos, Ischia Porto (NA), Italy

Giangrande, Adriana, DiSTEBA - Università di Lecce, Lecce, Italy

Hendler, Gordon, Natural History Museum, 900 Exposition Blvd., Los Angeles, CA 90007

Holbrook, N.N.,

Holland, William, Center for Coastal Fisheries and Habitat Research, NOAA, Beaufort, NC

Keel, Geoff, Smithsonian Institution, National Museum of Natural History, Department of Systematic Biology (Invertebrate Zoology), Washington, D.C. 20560-0163

Kibler, Steve R., National Ocean Service, NOAA, 101 Pivers Island Rd., Beaufort, NC, 28516

Knowlton, Nancy, Marine Biology Research Institute 0202 Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093 0202

Lemaitre, Raphael, Museum of Natural History, Department of Invertebrate Zoology, Smithsonian Institution in Washington D.C

Levitan, Don, Department of Biological Science, Florida State University, Tallahassee, FL 32306-1100

Litaker, Wayne, National Ocean Service, NOAA, 101 Pivers Island Rd., Beaufort, NC, 28516

Littler, Diane, Smithsonian Institution, National Museum of Natural History, Department of Botany, Washington, D.C. 20560-0166

Littler, Mark, Smithsonian Institution, National Museum of Natural History, Department of Botany, Washington, D.C. 20560-0166

Lovelock, Catherine, Centre of Marine Studies, The University of Queensland, Australia

Macintyre, Ian, Smithsonian Institution, National Museum of Natural History, Department of Paleobiology, Washington, D.C. 20560

Maldonado, Manuel, Department of Aquatic Ecology, Centro de Estudios Avanzados (CSIC), Acceso Cala St. Francesc, 14 E-17300 Blanes, Girona, Spain

McKee, Karen, U.S. Geological Survey, National Wetlands Research Center, 700 Cajundome Boulevard, Lafayette, LA 70506

Mays, Roger, Smithsonian Institution, National Museum of Natural History, Department of Systematic Biology (Botany), Washington, D.C. 20560

Mounts, Julie, Smithsonian Institution, Department of Vertebrate Zoology, Washington, D.C. 20560-0159

Norenburg, **Jon**, Smithsonian Institution, Department of Invertebrate Zoology, Washington, D.C. 20560-0159

Oftedal, **Olav T.**, National Zoological Park, Smithsonian Institution, Washington, D.C. 20013-7012

Opishinski, Tom, 81 Shippee Rd., East Greenwich, RI 02818

Ott, **Jörg & Renate**, Institute of Zoology, Department of Marine Biology, University of Vienna, Althanstrasse 14, A-1090, Vienna, Austria

Pandolfi, **John M.**, Centre of Marine Studies, The University of Queensland, Australia

Paul, **Valerie**, Smithsonian Marine Station at Fort Pierce, Fort Pierce, FL 34949

Piantoni Dietrich, **Carla**, Smithsonian Institution, National Museum of Natural History, Department of Invertebrate Zoology, Washington, D.C. 20560-0163

Richardson, **Sue**, Smithsonian Marine Station at Fort Pierce, 701 Seaway Drive, Fort Pierce, FL 22458

Riesgo, Ana, Department of Aquatic Ecology, Centro de Estudios Avanzados (CSIC), Acceso Cala St. Francesc, 14 E-17300 Blanes, Girona, Spain

Rittson-Williams, **Raphael**, Smithsonian Marine Station at Fort Pierce, 701 Seaway Dr., Fort Pierce, Fl 34949

Robles, **Rafael**, Department of Biology, Laboratory for Crustacean Research, University of Louisiana at Lafayette, Lafayette, LA 70504-2451

Ross, Cliff, Smithsonian Marine Station at Fort Pierce, 701 Seaway Drive, Fort Pierce, Florida 34949

Rotjan, Randi, Department of Biology, Tufts University, Medford, MA 02155

Ruess, Roger W., Institute of Arctic Biology, Department of Biology and Wildlife, University of Alaska Fairbanks, Fairbanks, Alaska 99775-0180

Ruetzler, Klaus**, Smithsonian Institution, National Museum of Natural History, Department of Invertebrate Zoology, Washington, D.C. 20560-0163

Sharp, Koty, Smithsonian Marine Station at Fort Pierce, Fort Pierce, FL 34949

Sherwood, **Craig* ,** 11 Farmington Ln., Sterling VA, 20164

Smith, David G., Smithsonian Institution, National Museum of Natural History, Department of Vertebrate Zoology, Washington, D.C. 20560-0106

Stake, **J.,** Department of Biology, PO Box 42451, Lafayette, LA 70504-2451

Steneck, Bob, University of Maine School of Marine Sciences, Darling Marine Center, Walpole, ME 05473

Tester, Patricia A., National Ocean Service, NOAA, 101 Pivers Island Rd., Beaufort, NC, 28516

Thomas, Jim, Nova University Oceanographic Center, 8000 N. Ocean Drive, Dania, FL 33004

Tyler, Diane, Smithsonian Institution, Smithsonian Institution Press, Victor Building, Suite 7100 Washington, D.C. 20560-0950

Tyler, Jim, Smithsonian Institution, National Museum of Natural History, Office of the Director, Washington, D.C. 20560-0106

Vandersea, Mark, 101 Pivers Island Road, NOAA Southeast Fisheries Center, Beaufort NC 28516

Wainwright, Peter, University of California, Davis, CA 95616

Weigt, Lee, Smithsonian Institution, NMNH-CORE Facilities, MSC, MRC 534, Maryland 20746-2863

Whigham, Dennis**, Smithsonian Environmental Research Center, P.O. Box 28, Edgewater, MD, 21037

Whigham, Mike, Smithsonian Environmental Research Center, P.O. Box 28, Edgewater, MD, 21037

Winston, Judy, Virginia Museum of Natural History, 1001 Douglas Avenue, Martinsville, VA 24112

Wulff, Janie, Department of Oceanography, Florida State University, Tallahassee, FL 32306

New web site address for the Environmental Monitoring Program at Carrie Bow Cay (T.B. Opishinski)

The new address for the web site is *http://cbc.riocean.com* Each of the topics listed below is accessed from the web site's Table of Contents.

New content:

1. 2006 Weather Statistics - View and download weather statistics for 2006. Weather statistics are available for viewing in HTML format or for download (PDF format) and for daily, weekly monthly and year-to-date time periods. Statistics are available for wind speed, air temperature, relative humidity, barometric pressure, solar radiation and rainfall rate. Wind speed and rainfall accumulation will be added to the list however they require different methods to process the data to yield meaningful information.
2. 2006 Tidal predictions - Tidal predictions for Carrie Bow have been generated for 2006. Predictions are calculated using a harmonic analysis model that utilizes past measurements of tidal elevation at Carrie Bow to forecast future tides for the Carrie Bow Cay area. The information is useful for planning the surveys and experiments that depend on the state of the tide. Water level measurements are overlaid on the forecasted tidal graphs for comparison.
3. Shoreline Surveys - Historical surveys have shown both seasonal and long-term changes occurring to the shoreline of Carrie Bow Cay. This page provides results of the latest shoreline survey of Carrie Bow Cay conducted in February of 2006 using GPS technology.
4. Four-Year Temperature Record - September of 2005 marked the 5th year since the monitoring system went into operation. The temperature record was constructed from data collected by the system.
5. 2005 Charts and Hurricanes - Although there were no direct strikes in Belize the effect of hurricanes in the region is observed in the environmental data. This section includes summary charts of water level and temperature for 2005. Charts are annotated with the names of hurricanes to identify their passing and to display the effects on water level and temperature.

Updated content

1. Environmental Data Archives - The quality of the historical data sets contained in the archives and the format of the page has been improved.

Some of the changes include:

-The order of the tables containing the download links was reversed so that the most recent year appears at the top of the page with tables for previous years following in chronological order.

-Data may still be downloaded in ASCII text or Excel format.

-An extensive effort was taken to process and improve the quality of the historical data sets. This primarily includes removing invalid data (spikes, data contaminated by biofouling) and correcting for normal instrument drift based on pre- and post-calibration processes. ***In general the data included in the ASCII text files is raw or has a minimal level of quality control while the Excel files contain data that of higher quality.

-The format of the ASCII text files has been changed to a tab-delimited format beginning in January 2006. The tab-delimited format offers increased readability in text editors and can be opened directly in Excel without having to using the import dialog.

-Graphs for each parameter have been added to the Excel archives.

2. Download Area maps - Maps that focus on southern Belize and the Carrie Bow Cay area are available to download. The maps are in PDF format and have been created from GIS images and hand illustrated research maps. Note that some of these files are large and can take a few moments to download to your web browser.

Future content

1. Links/Publications - NOT yet available, the objective of this section of the web site is to have descriptions of projects, links to related web sites, papers and presentations that have utilized the Carrie Bow data available for viewing or download. It is meant as a means to share information and generate new ideas. We are looking for additional references and papers to include in this section and welcome all submissions. A number of you have provided brief descriptions of your projects in the past and an expanded description or published paper would be
a welcome addition.
2. Other/User Suggestions - Much of the new content was created based on suggestions provided by scientists who have used the web site in the past. The input is invaluable and helps us create a better web site.

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Graphic Design: C. Piantoni.

Web Links to CCRE:

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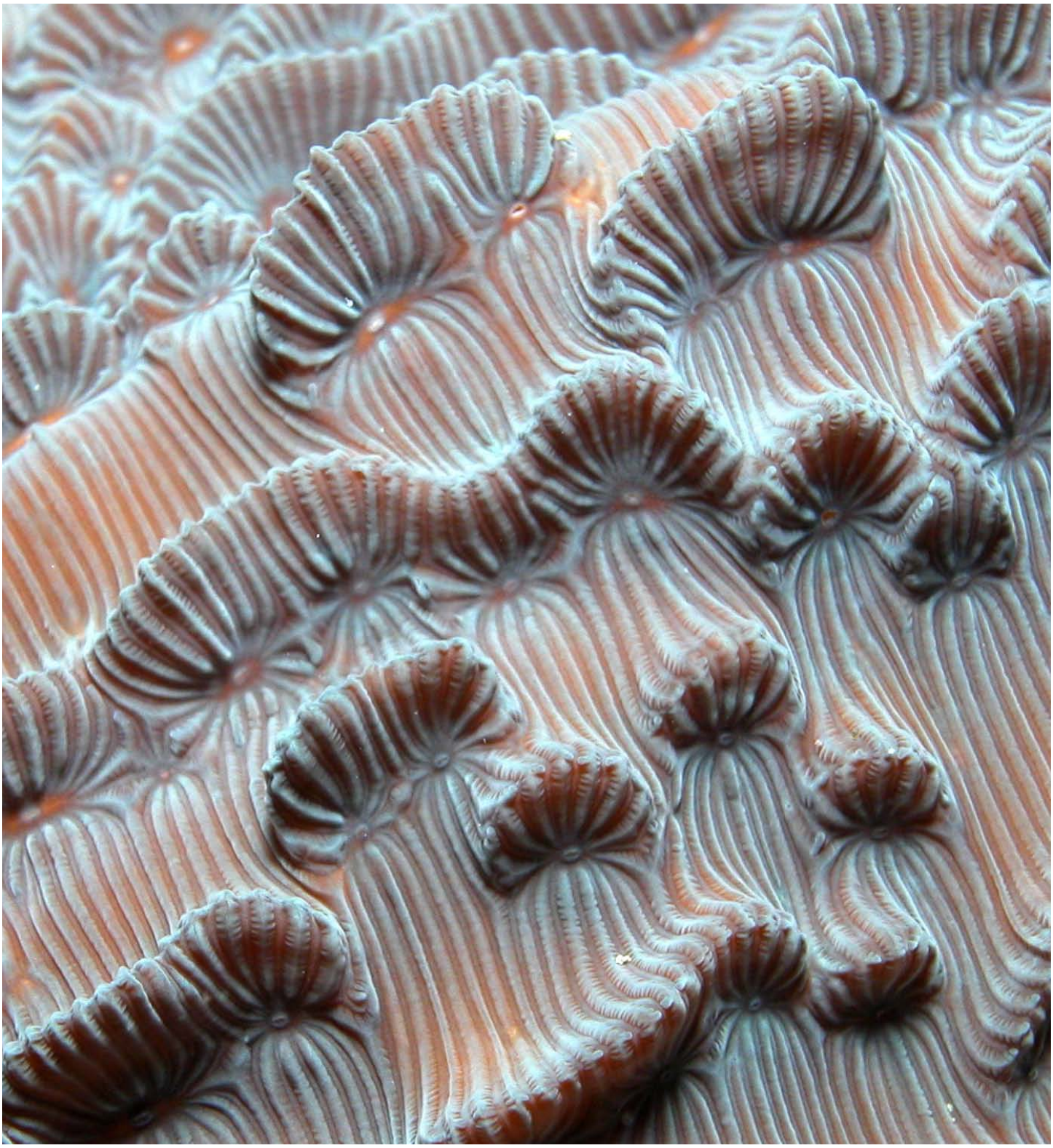

National Museum of Natural History
Caribbean Coral Reef Ecosystem Program
Washington, D. C. 20013-7012

CCRE Staff:

Klaus Ruetzler, Director
Mike Carpenter, Operations Manager
Carla Piantoni Dietrich, Research Assistant