



Smithsonian Institution

# *CCRE REPORT 2009*

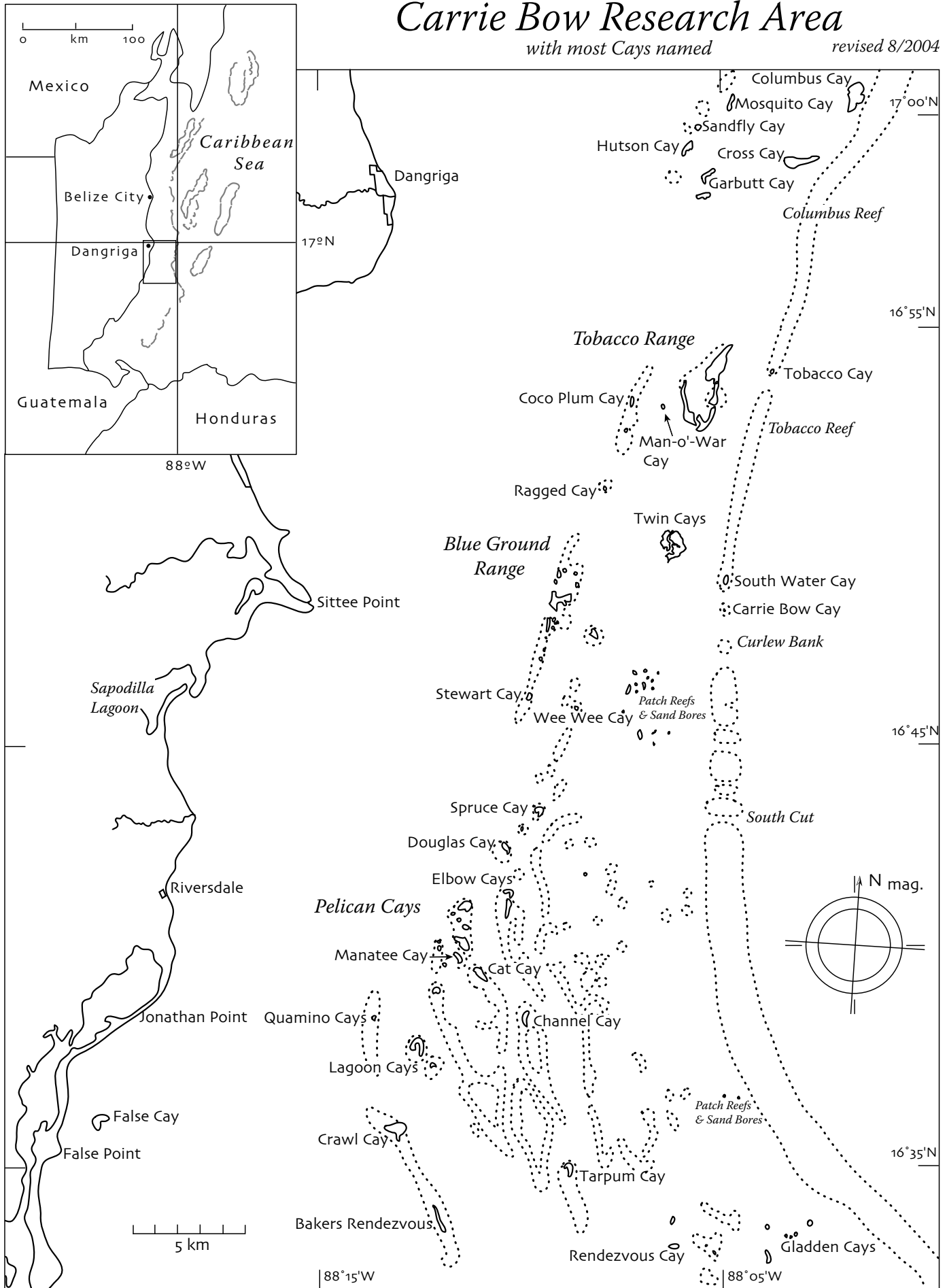
Caribbean Coral Reef Ecosystems • National Museum of Natural History

December 2009

# Carrie Bow Research Area

with most Cays named

revised 8/2004





*CCRE REPORTS*  
*2009*

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

December, 2009

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# CCRE News 2009

*This is the last CCRE Report issued by our current science management team. Starting with fiscal year 2010, Klaus Ruetzler will no longer head the CCRE program but continue his ongoing research on the biology and ecology of the Belizean barrier reef, particularly its rich sponge fauna. His position as CCRE Director will be taken over by Valerie Paul, Director and Head Scientist at the Smithsonian Marine Station at Fort Pierce (SMSFP), Florida. CCRE Operations Manager Mike Carpenter retired but will help hire and train his successor who too will be based at SMSFP. CCRE Research Assistant Carla Piantoni will return to graduate school in Brazil and pursue a career as biologist, specializing in herpetology. We are all grateful for the opportunities we had to facilitate and participate in reef and mangrove research in Belize.*

## Caribbean Coral Reef Ecosystems Octoberfest



Sponge Klaus and Marine Biologist Mike  
Cordially invite you to the first ever CCRE Octoberfest

Friday, 9 October 2009

3:00 - 5:00

Waldo Schmitt Conference Room

("Waldo's Tavern")

National Museum of Natural History

Donations most welcome

Program participants and supporters are welcome  
Snacks and refreshments provided

Klaus Ruetzler • 202.633.1766 • ruetzler@si.edu • No NMNH badge? We'll meet you at the  
Constitution Ave Entrance at 3:00 or call ahead for special arrangements.

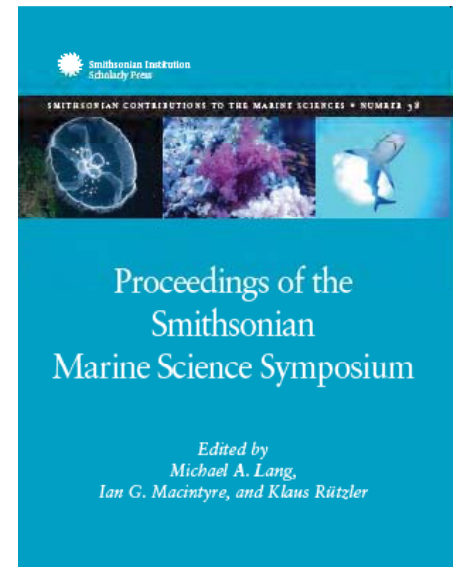
## CCRE Oktoberfest

Klaus Ruetzler, Research Zoologist and founding Director of the Caribbean Coral Reef Ecosystems Program in Belize, organized the "first CCRE Oktoberfest" gathering on October 9th, 2009 to celebrate the program and the people that made an impact on it over 37 years. Among those celebrated was newly retired Mike Carpenter who had been Operations Manager for 25 years- this in addition to many years of Museum work. He was given a painting created by Sandy Alenko (in attendance) illustrating a view from the field station's manager's room at Carrie Bow Cay looking westward toward the Belize mainland. The seafood feast and slideshow entertained all those attending including Smithsonian program staff, collaborators and station managers. A photo CD, including a slide show of historical snapshots of program participants and images from the party (the latter by Mary Parrish, Marilyn Schotte, and Yolanda Villacampa), is now available.



# Proceedings of the Smithsonian Marine Science Symposium

*The Symposium took place under the auspices of the Smithsonian Undersecretary for Science at the Ripley International Center in Washington, D.C. , in November 2007. In all, 38 contributions from the four Marine Science Network laboratories (SERC, Maryland; SMSFP, Florida; CCRE, Belize; and STRI, Panama) were accepted as manuscripts and published: Lang, Michael A., Ian G. Macintyre, and Klaus Rützler, editors. 2009. Proceedings of the Smithsonian Marine Science Symposium. Smithsonian Contributions to the Marine Sciences, No. 38. Washington, D.C.: Smithsonian Institution Scholarly Press. Contributions from the Carrie Bow Marine Field Station, operated by CCRE, made up more than half of the papers (see Publications), reflecting the diverse and challenging environment of the Belize barrier reef as well as the enthusiasm of CCRE program participants .*



## 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 pictorial 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 to microscopic 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 link to 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 Associates, 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 Carrie 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 facilities, 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.
- 2007 • Hurricane Dean strikes Northern Belize and Yucatan, Mexico (August), Felix passed over Honduras south of Belize (September); both cause major beach erosion at Carrie Bow Cay but no damages to buildings.
- 2008 • The Belize Minister of Natural Resources and his staff visit our facilities and tour the Pelican Cays to view damages caused by mangrove clear-cutting in





2009 this part of the Southwater Cay Marine Reserve.

- Ilka “Candy” Feller was offered again use of Light Hawk, a volunteer pilot-based organization at Lander, WY, to observe and photograph environmental damage to mangrove coast and cays.
- Proceedings of the first Smithsonian Marine Science Symposium highlight CCRE’s diverse contributions to our knowledge of the biology and geology of the Mesoamerican Barrier Reef, Belize
- Mike Carpenter retired after 25 years of service as CCRE Operations Manager and will build a new home in the woods of Georgia
- Klaus Ruetzler resigned as CCRE Director after 25 years in this position (and a total of 37 years as leader of the IMSWE, SWAMP, and CCRE programs). He will be followed by Valerie Paul of SMSFP.



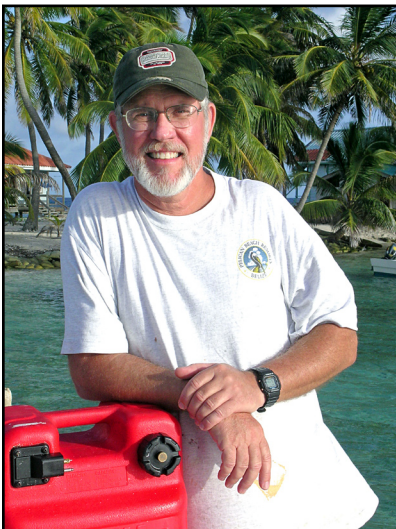
## Acknowledgements

*Our research is hosted by the Belize Fisheries Department and we thank Ms. Beverly Wade and Mr. James Azueta for collaboration 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; we greatly appreciate their many efforts: Jerry and Sandy Alanko, Sam Benson, Mike Carpenter, Earl David, Greg and JoAnn Dramer, Zack Foltz, Ed Hunt, Ed and Bonnie James, Scott Jones, Joel Leavitt, Dan Miller and Claudette DeCourley, Joel and Linda Moore, Keith Parsons, Gary Peresta, Tom Pezzella, Bert Pfeiffer, Craig Sherwood, Jim Taylor and Tanya Ruetzler.*

*Back in Washington, we thank Marty Joynt and Carol Youmans (Department of Zoology) for fund management, 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 grant funds and home-base facilities to aid our program.*

*The CCRE program is supported by a Federal appropriation complemented by the Hunterdon Oceanographic Research Fund.*



*I would like to take this opportunity to say thanks for the fantastic time I have had working with Klaus and with so many interesting researchers from all around the world. Thanks also to all my friends in Belize for making me a part of their beautiful country. Most of all, thanks to all the wonderful Station Managers without whose dedication and service none of it would have been possible. Thanks to all of you for making my years with CCRE such a rewarding experience. I am forever grateful to all of you...*

*Mike*

# Biodiversity and its Links to the Ecosystem

## Algae

### Magnificent dinoflagellates

M. Faust & S. D. Whittaker

Dinoflagellates form one of the most important components of plankton. They are primary producers of food that form important links in aquatic food webs. They are miniscule single-celled organisms, which swim freely in the water column. In the taxonomy of dinoflagellates, the cell covering plates, or theca, provides the most useful descriptive characters. The architecture of the plates determines overall shape of the cell defining the broad classification. Secondly, in armored dinoflagellates, the cell surface of the theca consists of cellulosic plates, and it is the number, shape, arrangement, and ornamentation of these plates which make possible the inner taxonomic separation. Some dinoflagellates are extremely beautiful; others are bizarre, while some are positively unique in shape. The morphology of dinoflagellates is varied as a quick glance at the plate illustrates.

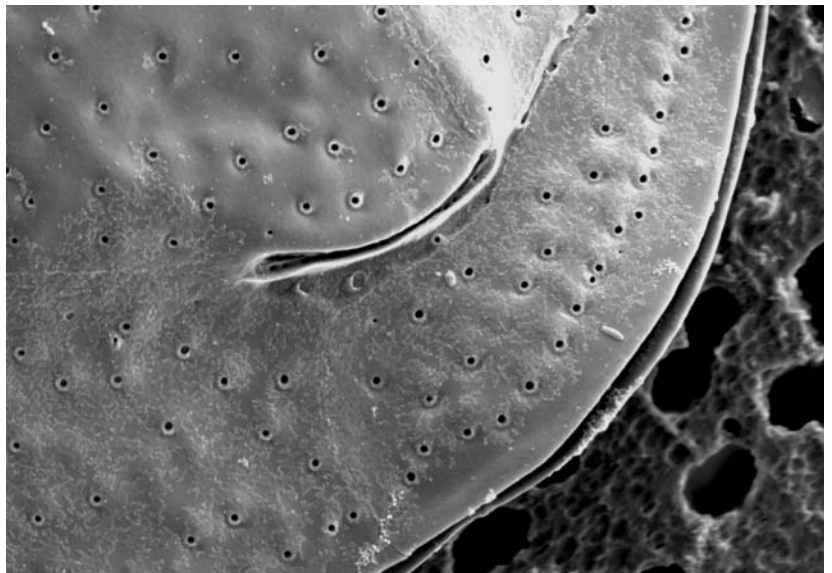
The scanning electron microscope - with superior depth of focus-ability to view the specimen from various angles, and increased resolution has provided to be of considerable value in identifying and illustrating the taxonomy of dinoflagellates. It enables us to see more clearly characters not visible by light microscopy, and also resolves finer details of the cell plate structures. At the same time we are able to appreciate the varied forms of these minute creatures and enjoy them as art forms which may give ideas or inspiration for quite unrelated activities. I hope that these micrographs will open up new vistas for many, besides providing a taxonomic reference for marine biologists. In the course of our research over two decades we have amassed a collection of some <8.000 scanning electron micrographs of tropical dinoflagellates.

The central role dinoflagellates play in oceans has accentuated the need for taxonomic studies. Surveys of dinoflagellates biodiversity in the Gulf Stream, Florida were carried out between 2001 and 2009 with the support of the Caribbean Coral Reef Ecosystem, and Marine

Science Network programs. In the dinoflagellate collections, at NMNH, identification of species is illustrated in state-of-the-art high definition digitized images with the scanning electron microscope. Sixty-four species represented by 21 genera were collected from the Gulf Stream water column (from 1-100 m) at three stations in 2009. The taxonomy of dinoflagellates exhibited diverse morphology, ornamentation and greater than 100 µm cell sizes. The diverse morphology of dinoflagellates shown on the attached plate is: *Ceratocoris armata*; *Protoperidinium crassipes*; *Protoperidinium obtusum*; *Ornithocercus thumii*; *Ceratium arietinum*, and *Dinophysis cuneus*.

Species recognized in the collections include: *Ceratium* (18 species) 6 of them rare species; *Ceratocoris* (5 species) 3 of them new species; *Ornithocercus* (3 species); *Protoperidinium* (7 species) with 2 new species being newly described. Harmful toxin producing species identified are: *Dinophysis mitra*, *Gambierdiscus pacificus* and *G. belizeanus*, and *Gymnodinium catenatum*.

Species recognized in the genera are *Blepharocysta*, *Dinophysis*, *Diplopsalis*, *Diplopsalopsis*, *Gonyaulax*, *Goniodoma*, *Oxytoxum*, *Phalacroma*, *Podolampas*, *Pa-leophalacroma*, and *Spiraulax*. Field guides for oceanic dinoflagellate species identification are being produced with scanning electron microscope images. A comparison of coastal oceanic dinoflagellates in SEM images from Bocas del Toro (144 species) and Carrie Bow Cay fore-reef (125 species) show some species similarities with other earlier studies reported in the Caribbean, Sargasso Sea, and Gulf Stream warm current and Belize.





# Floating detritus a specialized environment of harmful *Ostreopsis* dinoflagellates

M. Faust, W. Litaker, & P. Tester

Floating mangrove detritus is the habitat of benthic harmful dinoflagellates suspended in the water column, maintain high abundances and swim freely in the high energy low nutrient water off Carrie Bow Cay. These adhering organisms in the detritus initiate rapid growth rate proliferate and food source of meiofauna, or disperses by currents. *Ostreopsis* species are toxin producing dinoflagellates associated with ciguatera fish poisoning (CFP) in tropical waters at Belize. A major goal of this year's research was to reassess our initial comparison of the affect of temperature on the abundance of *Ostreopsis* species in floating detritus.

The data indicate an increase in *Ostreopsis* abundance in floating detritus at warm 30 to 32 °C water temperatures. In May 2009 eight species of *Ostreopsis* is identified: *O. marinus*, *O. siamensis*, *O. ovata*, *O. labens*, *O. lenticularis*, *O. caribbeanus*, and *O. belizeanus* and *Ostreopsis* sp. nov. The mean cell density of dinoflagellates ranged from 60 to 85 cells x ml<sup>-1</sup> in floating detritus that represents 79% of total dinoflagellates. In 2008 seven *Ostreopsis* species identified in floating detritus; cell concentration estimated 58 to 83 cells x ml<sup>-1</sup> in floating detritus, and *Ostreopsis* species represented 76% of the total dinoflagellate populations. In both collections, *Gambierdiscus* (2 species) and *Prorocentrum* (3 species) was identified and cell concentrations of both species depressed. A new species, *Ostreopsis* sp. nov., was discovered in the collections. Cells are tear-shaped in apical view and a curved narrow apical pore plate is present.

Result indicate that high water temperatures stimulated the growth rate of eight *Ostreopsis* species, whereas, it depressed growth of *Gambierdiscus* and *Prorocentrum*. Knowing the distribution of CFP-dinoflagellates as producer of toxins is important and yet has to be fully characterized in tropical waters.

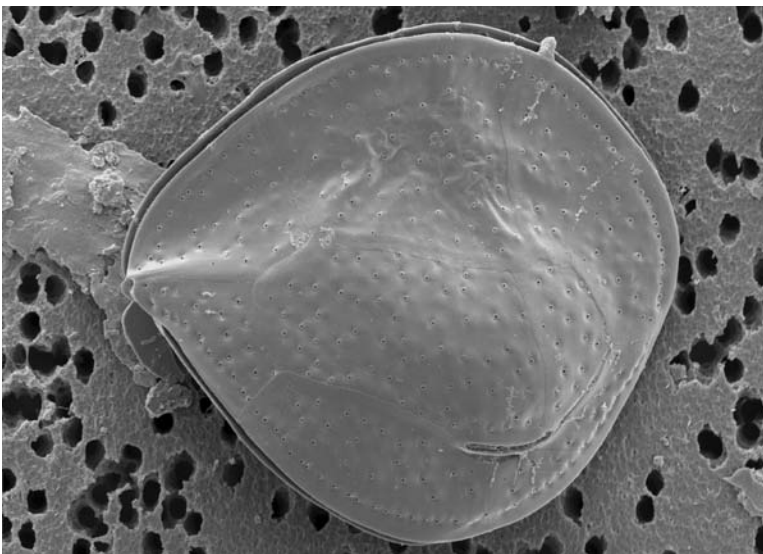
## Distribution and abundance of ciguatera fish poisoning in Belize and Fort Pierce

P. Tester, W. Litaker, S. Kibler, M. Vandersea, & C. H. Faust

Tropical dinoflagellates in the genera *Gambierdiscus*, *Ostreopsis* and *Prorocentrum* produce toxins that bioaccumulate in marine food webs causing ciguatera fish poisoning (CFP), the most common non-bacterial food poisoning in the world. Of these, species belonging to the genus *Gambierdiscus* are thought to be the most important contributors to CFP. A major goal of this year's research was to complete our initial comparison of the distribution and abundance of CFP causing organisms in Belize relative to the regions around the Smithsonian field station at Fort Pierce. Analysis of the samples processed to date indicated that in Belize, *Gambierdiscus* species prefer low flow, high nutrient systems, whereas *Ostreopsis* species favor higher flow lower nutrient areas. *Prorocentrum* species appear to do equally well in both these environments. Preliminary data indicate that the *Gambierdiscus* species composition is similar between Fort Pierce and Belize, but that the abundances are much lower in Fort Pierce. There are also notable differences in distribution. In Fort Pierce, the *Gambierdiscus* species were absent in the lagoon regions despite their superficial resemblance

to the Belizean mangrove embayments which foster high *Gambierdiscus* densities. The literature indicates that this absence is most likely due to the intolerance of *Gambierdiscus* species to the types of salinity fluctuations which occur in the Ft. Pierce Lagoons. *Gambierdiscus* species are instead associated with macroalgae growing along rock outcroppings that run parallel to the coast on the ocean side of the barrier islands. Overall, *Ostreopsis* is most abundant CFP dinoflagellate in the Fort Pierce lagoon system, and is associated with local macrophytes and seagrasses.

Another major goal of this year's work was to evaluate whether small uniform pieces of window screen, which act as artificial seaweeds, will accu-





mulate *Gambierdiscus* cells in proportion to the densities found on surrounding algae when placed in the environment for a 24 hour period. If a good correlation is found, this simple technique could revolutionize our ability to monitor these harmful algae. The preliminary results indicate that the window screen sampling devices do good job of reflecting the densities of *Gambierdiscus* and *Ostreopsis* species in the environment, but that they systematically underestimate the numbers of *Prorocentrum*. However, the good correlation between screens and algal counts indicates that the screens will prove a useful in screening the relative distributions of species from all three genera and that the estimates for *Gambierdiscus* and *Ostreopsis* will be quantitative. Molecular analyses are underway to determine if the species composition from the algae and screen samples is the same. The data also indicate a significant decline in *Ostreopsis* abundance with depth and that *Gambierdiscus* abundances are still relatively high even at approximately 20m depth. This implies that significant accumulation of toxins might occur deeper in the water column, and not only in the upper few meters as is often assumed.

The sampling this year also revealed a significant *Gambierdiscus* bloom in Douglas Cay (DC). The genetic composition of this bloom is being determined and will be compared with a similar bloom that occurred in 2006. The 2009 bloom was heavy enough to produce a mucous net over much of the benthos. Knowing which species are most abundant during the two blooms may provide an indication as to which species are most likely to form toxic blooms in the Caribbean.

The proximity of Fort Pierce to the Gulf Stream also made it possible to sample this unique environment to characterize the dinoflagellates present. A preliminary analysis has

shown a number of dinoflagellate species formally unknown in Ft. Pierce waters.

Another goal was to complete development of the quantitative PCR (qPCR) assays for the six known *Gambierdiscus* species and to use them to analyze field samples for species abundance and distribution. The assays have been completed, thoroughly vetted and are now being used to analyze the 2009 samples. We aim to better characterize any similarities or differences in relative species composition between Belize and Fort Pierce, to determine if the species composition from the shallower vs. deeper sites is significantly different and to characterize cultures which were isolated from each environment in order to identify any new species. A phylogenetic analysis of data obtained after last year's report indicates that at least two new and as yet undescribed *Gambierdiscus* species (ribotypes 1 and 2) occur in these habitats

## Porifera

### Report advances Carrie Bow sponge community condition

*E. Villamizar & M. C. Diaz*



Compared with the large number of coral-disease studies, knowledge of sponge syndromes or diseases is scarce. Probably the generally smaller size and scattered distribution of sponges, compared with reef corals, is the reason for the neglect.

Eight hundred sixty six sponges representing 56 species were examined along the different zones of the barrier reef at Carrie Bow Cay. The most abundant were *Niphates erecta* (8.8%), *N. digitalis* (6.7%), *Aiolochoira crassa* (7.4%), *Ircinia strobilina* (5.8%), and *Agelas wieden mayeri* (5.8%). Less abundant species (but >4%) were *Aplysina fistularis*, *A. archeri*, *Svenzea zeai*, and

Investigating taxonomic uncertainty in the sea anemone genus *Lebrunia*

A. L. Crowther

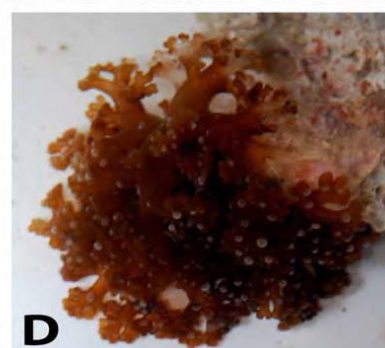
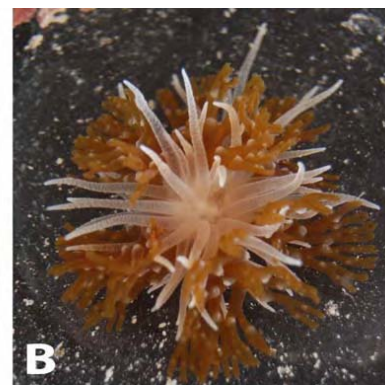
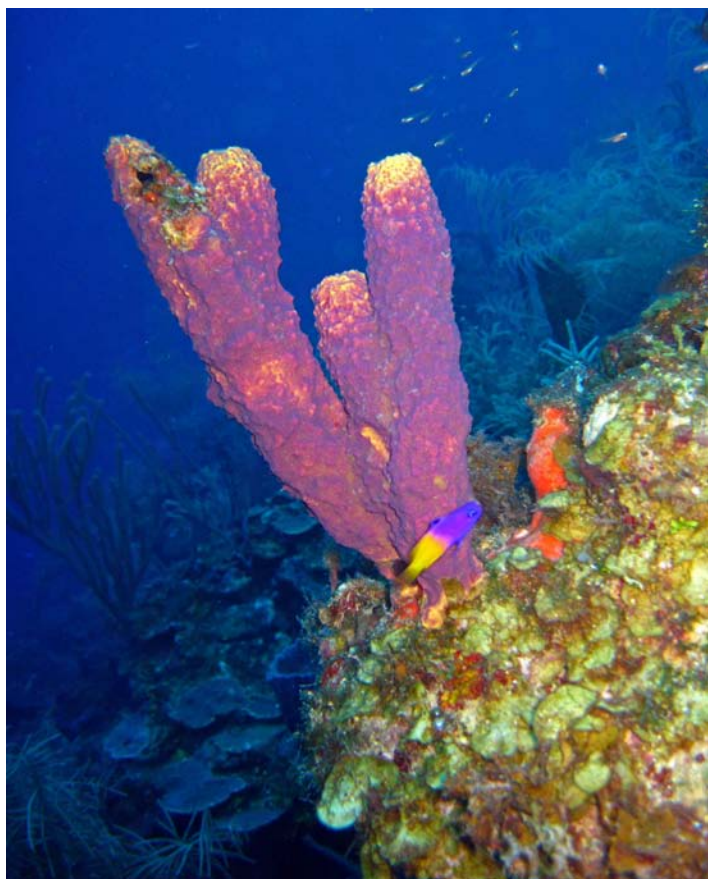
In current classification, the sea anemone genus *Lebrunia* (family Aliciidae) has two valid species, *L. danae* (Duchassaing and Michelotti, 1860) and *L. coralligens* (Wilson, 1890). My trip to the Smithsonian Institution Carrie Bow Marine Field Station was part of a larger field trip in the Caribbean Sea to collect specimens of both currently valid species of *Lebrunia*. The two species have similar distributions, and the main difference between them is the size of the individual; specimens identified as *L. danae* are generally larger than specimens identified as *L. coralligens*. I am testing the hypothesis that instead of two valid species of *Lebrunia*, there is in fact just one, and the name *L. coralligens* had been applied to juvenile specimens of *L. danae*.

While at Carrie Bow, Luciana Gusmão and I surveyed and collected specimens of just one size class of *Lebrunia* specimens. At Carrie Bow we observed similar reefal formations and microhabitats (e.g. multiple individuals of *Lebrunia* attached in crevice of *Porites* sp. boulder) to what we had observed in Barbados and Curaçao, however, no small specimens were found. In Barbados and Curacao, we observed small and large

*Xestospongia muta*. Depending of section of the reef, the values may change, however, the species *N. erecta*, *N. digitalis*, *A. crassa* and *Xestospongia muta* have an important presence (>4%) in all zones.

Of the 56 species examined, only nine showed signs of a possible disease: *Aplysina archeri*, *A. cauliformis*, *A. fistularis*, *Callyspongia plicifera*, *I. strobilina*, *I. felix*, *I. campana*, *Sidonops neptuni* and *X. muta*.

In all, 95 specimens showing lesions were examined but estimated prevalence values were rather low for most. On the inner fore reef, the highest incidence value was for *S. neptuni*, however we did not observe signs of a true disease in this species; the main problem was overgrowth by algae. In *A. cauliformis* we found several cases of advanced decay, probably the result of *Aplysina* Red Band Disease; but still, the number of incidences was low (only 3 during the course of the survey). On the outer fore reef, incidence of sponges with some evidence of disease was even lower, except in *A. fistularis* where 14 specimens showed some indications of possible disease.





specimens of *Lebrunia* co-occurring at the same locality. From this, we inferred that there are in fact two valid species, and *L. coralligens* (with smaller specimens of the two species), does not occur this far west in the Caribbean Sea.

We collected seven specimens of *L. danae* at Carrie Bow Cay, and observed the morphology of the pseudotentacles. Specimens of the genus *Lebrunia* possess outgrowths of the column wall called pseudotentacles. Specimens of *Lebrunia* possess branched outgrowths of the column wall called pseudotentacles, so called due to their resemblance to tentacles. The pseudotentacles harbor zooxanthellae, and therefore their inferred function is to increase surface area. Vesicles —spherical structures dense with nematocysts — defend the pseudotentacles. Variations in the branching and placement of the vesicles change the overall appearance of the pseudotentacles. Compared to the other localities surveyed in the Caribbean, the specimens from Carrie Bow had the greatest diversity in appearance. It has been previously proposed that individuals of *Lebrunia* are involved in mimicry, in particular of algae. In the field, the specimens had the appearance of different species of algae: A) looked similar to *Halimeda* sp. B) looked similar to *Laurencia intricata* C) looked similar to *Trichogloea* sp. D) another specimen that had slightly different pseudotentacle morphology to the others.

## Annelida

### Marine catenulida (Platyhelminthes) of the Carrie Bow region

W. E. Sterrer

In 1974, Sterrer & Rieger described the new marine family Retronectidae within Turbellaria-Catenulida, with two genera (*Retronectes*, with 5 spp., and *Paracatenula*, with 4 spp.), of which the latter genus lacked a mouth, pharynx and gut lumen. Subsequently, Ott *et al.* (1982) showed that these (and other) mouthless worms lived in symbiosis with prokaryotes (alpha-proteobacteria), which allows them to take advantage of the sulfide system in marine sediments.

Over the last few decades we have been finding, in the region of Carrie Bow Cay, several known plus more than half a dozen new species of *Paracatenula*, at least one of which already figured prominently in a

student thesis (Steiner 2002). During a 2 week period in March 2009, Jörg Ott (University of Vienna) and I collected sufficient material for a description/re-description of all Belizean Retronectidae.

### Distribution and abundance of trematode parasites in the mangroves

M. Torchin & O. Miura

Parasites are often neglected in studies of biodiversity and ecosystem function since they are generally small relative to their hosts and not easily observed. However, they are often common and can comprise substantial biomass, particularly in estuarine systems. In fact, recent studies suggest that they can exceed the biomass of top predators and are responsible for most of the linkages in some coastal food webs. Thus, they require more attention in studies of biodiversity and ecosystem function. As part of a latitudinal study evaluating the relative importance of allopatric versus non-allopatric mechanisms driving diversification in marine snails and their trematode parasites across oceans, we evaluated parasitism in five species of common coastal Cerithioidean snails in the Carrie Bow area. Here we report on the distribution and abundance of trematode parasites in these snails.

We focused our efforts within mangrove habitats as these systems are important foci for parasite transmission. To increase our understanding of the marine biodiversity in the vicinity of Carrie Bow Cay, we dissected over 3,500 snails and recorded at least 20 different trematode species across 10 sites to provide







from subtidal habitats in reef rubble and on sand bores near the Smithsonian Institution Carrie Bow Cay marine station (CBC1).

### Distribution and abundance of trematode parasites

Snails were kept alive until we dissected under a stereomicroscope. Parasites were identified with the aid of a compound microscope and published literature. We dissected 3,343 *Cerithidea pliculosa*, 110 *Cerithium lutosum*, 100 *C. atratum*, 90 *C. litteratum* and 150 *Batillaria minima*. In total, we found 20 trematode species across 10 sites.

As we expected, the mangrove dwelling *Cerithidea pliculosa*, was host to the most diverse suite of trematode parasites. We found 15 species of trematodes infecting *C. pliculosa*. The most common species were; a philophthalmid, *Parorchis acanthus* which was abundant in Tobacco range and on the mainland and a heterophyid, *Euhaplochis californiensis* which was abundant in Twin Cay. *Catantropis johnstoni* was common only on Twin Cay.

Trematode prevalence was higher on the mainland, where up to half (49 %) of snails were infected (Main3), compared to the islands (Twin Cay and Tobacco range) (chi-square test,  $P < 0.01$ ). This could be driven by relative differences in the abundance and species richness of birds, since birds transmit the parasites to snails and have been shown to drive infection patterns in snails. All snails and parasites were preserved in EtOH and stored at  $-20^{\circ}\text{C}$  in a freezer for molecular analyses. While the molecular analyses are still ongoing we have identified several cryptic parasite species within some of the trematode morphospecies examined suggesting that parasite diversity is probably substantially higher than what we report. The other snail species were not as heavily parasitized. We found 4 species of trematodes in *Cerithium lutosum* and only one species in *Batillaria minima*. *Cerithium atratum* and *Cerithium litteratum* were not infected.

Parasite prevalence and species richness was highly variable among the snail species and across sites, probably due to the distribution of their hosts. Trematode parasites are common in these mangroves- we recorded at least 20 different trematode species in 3 snail species across 10 sites. This demonstrates the potential for future research on the ecology of infectious agents and their interactions with several other species within the mangroves islands in Belize.

a baseline of parasite species richness and abundance for the area. Trematode parasites have complex life cycles and depend on several host species at different trophic levels to complete their life cycle. Thus, they fundamentally integrate interactions among several free-living species within the mangrove. They generally require a specific snail host in which they undergo asexual reproduction, then infect a second intermediate host (fishes, crustaceans and mollusks are common hosts) that will be preyed upon by a bird that serves as the definitive host in which the parasite reproduces sexually. This invariable links species (and trophic levels) within a mangrove by a common thread- their parasites. In fact, the presence of these parasites has been proposed as a way to measure ecosystem health with lower parasite diversity in systems heavily degraded by humans. This has yet to be tested for Belize.

### Common Cerithioidean snails in CCRE

We encountered five common Cerithioidean snails from intertidal and subtidal mangrove and reef rubble habitats near Carrie Bow Cay. *Cerithidea pliculosa* was abundant in the mangroves on Twin Cay, Tobacco range and within lagoons near Hopkins on the mainland. The snail was common in open areas in the high intertidal zone and shallow channels within the mangroves. We found three populations of *C. pliculosa* on Twin Cay (Twin1, 2 and 4), two populations on Tobacco range (Tobacco1 and 2) and three populations on the mainland (Main1, 2 and 3). *Cerithium lutosum* and *Batillaria minima* were also abundant in open areas and near the edge of mangroves in Twin Cay. We also found a small population of *Cerithium lutosum* at Twin1. *Batillaria minima* was very abundant at Twin3 and 4. We collected *Cerithium atratum* and *Cerithium litteratum*

## Crustacea

### Guidebook to decapod crustaceans of Carrie Bow Cay, Belize, and vicinity - intertidal to shallow subtidal waters

D. L. Felder, E. Palacios Theil, B. Thoma, J. M. Howell Felder, & S. DeGrave

Collections were again focused on and immediately around Carrie Bow, Twin Cays, and shoals along South Water Cay. Extensive collections 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 and 2007 trips contributed extensively to a collection 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, for which over 1500 photographs were accumulated. Over 1400 additional decapod crustacean photographs by DLF were added by the present effort, samples of which are here attached, and the project was expanded to include participation of S. De Grave in authorship of the guidebook. With his addition to the team, new effort was put into more comprehensively covering the caridean shrimp, as well as other decapod groups. To that end, he and DLF have begun work on an initial paper describing new species of *Processa* from the region. Progress was also made on other project elements proposed by DLF, including the continued obtaining of genetic samples for selected groups of burrowing thalassinideans (with associates), majoid crabs, xanthoid crabs, pinnotherid crabs, and porcellanid crabs that are under study; all objectives on this front were met. Return to several sites near Carrie Bow also allowed DLF to confirm previous observations bearing on the non-indigenous species *Charybdis hellerii*, and to add several records to reports of thalassinideans from the region that were already in press (that "Note added in press" ap-

pended below).

At least one follow-up trip will be required for additional work on and around Twin Cays and Carrie Bow if these areas are to be adequately represented in the envisioned guidebook. Intertidal, shallow subtidal snorkeling, in addition to shallow SCUBA sampling will be required. This is particularly important to assure adequate coverage of caridean fauna, now that we have committed to inclusion of this group

in the field guide. Work present continues on efforts to describe and name a number of new taxa, as this must be completed in advance of the regional guidebook.

#### "Note added in press:

Additional sampling in Belize was conducted in February 2009. Observations in shallow waters at Twin Cays confirmed that populations of *Charybdis hellerii* remained as seen in 2007. Further sampling for thalassinideans supported accounts on the preceding pages, with noteworthy additions. Sampling among shoreline mangrove roots at Twin Cays produced the first speci-

mens of the Axianassidae, all apparently representing an undescribed species of the genus *Axianassa*. Five such specimens were extracted by yabby pump from deep beneath <0.25 m<sup>2</sup> of surface area at low tide, but less productive adjacent sampling suggested





heterogeneous patterning. Given the small size of these specimens, we question whether this species accounts for burrows provisionally attributed to *A. australis* on the basis of castings mentioned on the preceding pages. From these same habitats at Twin Cays, the first specimen of the callianassid *Biffarius fragilis* was captured, along with a specimen of the same *Naushonia* sp. reported from Carrie Bow Cay on preceding pages. Finally, the first specimen of the family Callianideidae, *Callianidea laevicauda* Grill, 1959, was taken from intertidal rubble of the exposed reef crest at Carrie Bow Cay. These latest efforts confirm presence of at least one species of the family Axianassidae, add a seventh thalassinidean family to our report, and bring the documented number of thalassinidean species in our survey to at least 19.”

## Pisces

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

J. C. Tyler

We assessed ichthyofaunal diversity within offshore mangrove cays in Belize during three, two-week surveys (2003, 2004, 2005). 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 2,586 gear sets was completed and 8,131 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 presenting the best conditions and sinkhole the worst. 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.

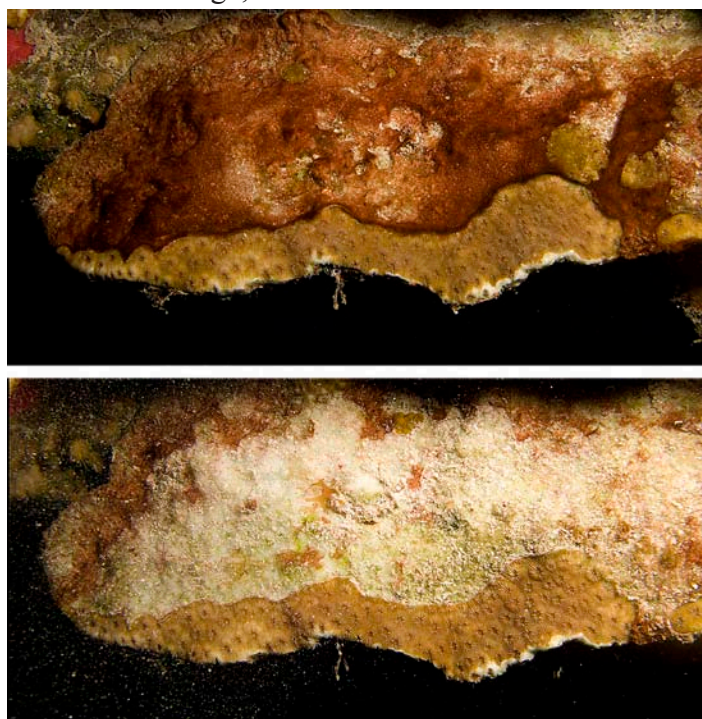
## Microevolution

Monitoring taphonomic-process initiative, and maintain bottom-up vs. top-down experimental plots; examining the status of the spur-and groove system after twenty five years; and work on the revision of Caribbean reef plants

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

Fourty two experimental replicates (sections of corallines versus corals) were scanned and evaluated including 30 samples from the fore-reef crest, 16 from the back-reef site, and 16 from the 15-m deep reef-ridge site. This experiment is designed to address the “co-

nundrum of the corallines”, which arises from the observation 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 isolated formations. We hypothesize that this mysterious disappearance during fossilization is due to differential taphonomic



Toxic Cyanobacteria overgrowing living coral. Bottom: Coral after the removal of the toxic Cyanobacteria; all of the coral under the blue-green alga is dead.



processes. Many rock-boring and limestone altering creatures abound on coral reefs; including one of the most important groups of limestone altering organisms, 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. Our preliminary results indicate that, although a slow process, this appears to be the case, potentially explaining the enigmatic disappearance or alteration of massive/extensive deposits of coralline algae in the fossil record.

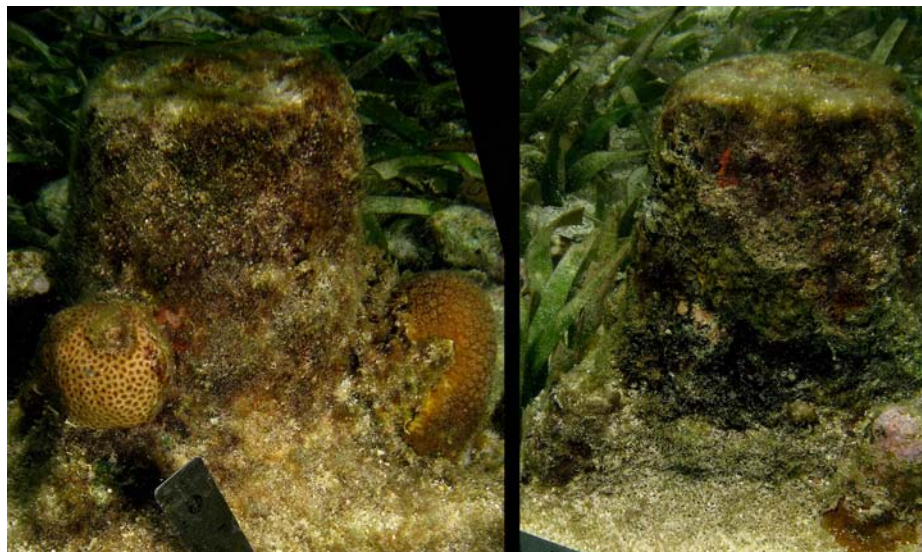
#### **Nutrient experiments**

– Due to the growing problems associated with eutrophication and overfishing throughout tropical and subtropical shorelines, the ecological responses of coral reefs and macroalgae to nutrient enrichment and release from predation have been repeatedly cited as priority

areas in need of further research. The conflicting reports in an issue of *Science* (Jackson et al. 2001) and another study (Miller et al., 1999) refuting the nutrient component of our relative dominance model, but using tree stakes as fertilizer (containing up to 6% of the algicide chlorine), have only served to “muddy the water”. The CCRE research we published recently reveals the flawed experimental evidence purported to refute the RDM. By avoiding the use of inappropriate sources of enrichment documented above, we have completed ecologically realistic experiments that provide new insights into the complex nutrient status of Caribbean coral reefs. These results have already been used in is considered to be a seminal paper to clarify worldwide understanding of the ecology and sustainable management of coral-reef ecosystems.

The team monitored and re-assessed the 16 (4 sets of 4) previously pulsed replicates (ambient, P, N, N+P) set up in 2007 on the CBC back reef flat northeast

of the laboratory in an area of documented moderate herbivory. All of these were re-photographed on four sides to provide 64 quantitative samples. The findings show a marked, but highly-complex, effect of nutrients in that increases in bottom-up nutrient controls and their interactions stimulate harmful algal blooms (that can alter the abundance patterns among functional groups, even under herbivory); conversely, elevated nutrients inhibit the growth of ecologically beneficial reef-building corals. These results demonstrate even further complexity in that nutrients also act directly as either limiting factors (e.g., physiological stresses) or as stimulatory mechanisms (e.g., growth enhancing factors), as well



Nutrient diffuser with DIN (nitrogen) added showing healthy algal turf community and living coral. Right: Diffuser with SRP (phosphorus) added showing harmful bloom of Cyanobacteria (blue-green algae) with coral mortality.

as functioning indirectly by influencing competitive outcomes. Herbivory directly reduces fleshy-algal biomass, which indirectly (via competitive release) favors the expansion of grazer-resistant reef-building corals and coralline algae. Because of the sensitive nature of direct/indirect and stimulating/limiting interact-

ing factors, coral reefs are particularly vulnerable to anthropogenic reversal effects that decrease top-down controls and, concomitantly, increase bottom-up controls, dramatically altering ecosystem resiliencies. This work has been recently accepted for publication in the journal “Harmful Algae”.

During 2006, five experimental sets of four diffusers were moved and securely fastened to the high-energy zone of highest herbivory seaward of the reef crest. Changes in cover of each algal-group/coral interaction, as well as recruitment, again were recorded by photographic sampling of each of the four sides of the diffuser arrays, projecting the images in the laboratory, and scoring changes in the percent cover of predominant taxa. As mentioned, the early results are encouraging 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. One particularly exciting finding is that SRP

alone appears to be responsible for blooms of certain harmful blue-green algae (Cyanobacteria) that are then inhibitory to reef-building corallines. We will continue to monitor critical succession/competition interactions among these most important of reef-producers.

## Evolution and biodiversity of sea anemones (Cnidaria: Actiniaria) symbiotic with hermit crabs

L. C. Gusmão

The main goal of my fieldwork in Carrie Bow – Belize was to collect individuals of the sea anemone species *Calliactis tricolor*. This species is frequently found living on shells inhabited by hermit crabs. *C. tricolor* has been originally described from Barbados but its range is very broad spanning the Caribbean Sea and the Gulf of Mexico. These individuals would be the subject of a molecular study to evaluate the genetic diversity within this species and would complement a broader molecular study of a closely related species, *C. polypus*, from the Pacific Ocean and Indian Ocean. While in Carrie Bow, extensive intertidal, as well as snorkels and seven dives (5-25 meters), including one night dive, was carried out, but I was not able to collect any specimen of *C. tricolor*. Although previous reports listed this species as moderately abundant in the Caribbean, *C. tricolor* was not found in either Curaçao or Barbados during the Summer of 2009. This makes me think that there might be some degree of hermit crab migration that makes collection of these animals harder during this period of the year.

Although the target species of my project was not found, other species of sea anemones were collected for posterior morphological and molecular studies. A total of seven species of sea anemones were collected (see list below) in the intertidal lagoon east of Carrie Bow and on reefs around the island. Anemones were kept alive in aquaria for morphological study and characters such as color, number of tentacles and posture were examined. At least one specimen of each species was fixed in formalin for detailed morphological and histological examination at the Invertebrate Zoology Laboratory at the Ohio State University. One specimen or a small piece of tissue was collected from each species and fixed in 100% ethanol for molecular study. DNA will be extracted using a Qiagen Kit and PCR amplification and sequence of three mitochondrial (12S,

16S, COIII) and two nuclear markers (18S, 28S) is currently being carried out. Sequences from species collected in Carrie Bow Cay will be included in a broad phylogenetic project of sea anemones (Cnidarian Tree of Life Project – NSF).

## Phylogenetic constraints on community assembly in a group of neotropical coral reef fishes

R. I. Eytan

Why are there so many species of coral reef fishes? How are they able to co-exist without competing one other out of existence? The first question is an historical one. The species that exist in a local community are drawn from a regional species pool, which arises through speciation over geological time scales. The second question applies to processes such as dispersal, competition, and microhabitat use that occur on ecological time scales.

The interaction of historical and ecological processes can help explain co-existence. On the one hand, it may be expected that closely related species are similar to one another in their ecologies, so that phylogenetic distance among reef fish species in a community limits their co-existence. On the other hand, closely related, coexisting species may segregate along one or more ecological axes to allow co-existence. This segregation should be greater than expected under a neutral process where ecological differences increase along with phylogenetic distance.

I have tested these hypotheses on the constraints and facilitation of reef fish community assembly in a genus of tube blennies, *Acanthemblemaria*. These are small reef fishes (14 -45 mm in length) with a Neotropical distribution. They make their homes in vacated invertebrate holes in corals and other hard substrates. Previous studies have demonstrated that some *Acanthemblemaria* species finely partition microhabitats and that congeners that co-occur sometimes compete for the same holes, with metabolic rate mediating the competitive outcomes. I have taken advantage of the large number of co-occurring *Acanthemblemaria* species on the Belizean barrier reef to characterize the microhabitats and metabolic rates of these fishes.

This research was carried out at the Carrie Bow Cay field station in December 2008. Over the course of a month microhabitats were characterized for seven blen-



ny species using underwater surveys. In addition, fishes were collected and metabolic rates were measured. Preliminary results indicate that some closely related species are more different from each other in metabolic rate or microhabitat occupancy than expected from a random process. However, species differed either along an axis of ecological differentiation or metabolism, not both. This result suggests that in the absence of ecological differences among closely related species, competitive ability (as mediated by metabolism) becomes more unequal. Further analyses will determine how microhabitat use and metabolism have evolved over time by mapping these traits onto a molecular phylogeny of the genus *Acanthemblemaria*.

## Reproductive and Developmental Biology

### Comparisons of settlement and recruitment among spawning and brooding corals in the Caribbean

V. J. Paul, R. Ritson-Williams, S. Arnold, & R. Steeneck

Coral reefs throughout the Caribbean are experiencing an unprecedented decline in coral populations. One potential natural process of recovery is coral settlement and post-settlement survival. We tested the settlement specificity of three spawning Caribbean corals, *Acropora palmata*, *A. cervicornis* and *Diploria strigosa*, and the brooding coral *Favia fragum* by measuring their rates of larval metamorphosis in response to crustose coralline algae (CCA) and other substrata in choice and no-choice assays. In no-choice assays the coral larvae were placed in six treatments: filtered seawater (FSW), a fragment of biofilmed dead skeleton of *A. palmata*, or a fragment of one of four species of CCA (*Hydrolithon boergesenii*, *Porolithon pachydermum*, *Paragoniolithon solubile*, and *Titanoderma prototypum*). Within each CCA treatment there were three different substrata to settle and metamorphose on: 1) the CCA surface, 2) the rock under the CCA, or 3) the plastic petri dish. The four day old larvae of *D. strigosa* had higher total settlement and meta-

morphosis (all substrata combined) in the presence of *H. boergesenii* and *T. prototypum* than in the treatment with a biofilmed limestone. The five day old larvae of both *A. palmata* and *A. cervicornis* had similar rates of total metamorphosis (all substrata combined) in all treatments (excluding FSW) even in the absence of CCA. The two day old *Favia fragum* larvae had higher total settlement on *T. prototypum* and a biofilmed rock than in response to *P. pachydermum*. For all of the larvae tested they could discriminate among CCA species, and they metamorphosed on different substrata in the presence of different CCA species. The larvae of all four coral species had higher rates of metamorphosis on the top surfaces of *H. boergesenii* and *T. prototypum* than on *P. pachydermum*.

In choice experiments the coral larvae were offered a choice between two species of CCA in the same dish. When given a choice, *A. palmata*, *A. cervicornis*, *D. strigosa* and *F. fragum* larvae had more settlement and metamorphosis on the surface of *H. boergesenii* or *T. prototypum* or clean rock than onto the surface of *P. solubile*. When given a choice between *H. boergesenii* and *T. prototypum* there was no difference in the amount of settlement and metamorphosis onto their surface for any of the larvae except for *A. palmata* which had higher rates of settlement on *H. boergesenii*.

To determine if the survival of newly settled corals in the field is a significant bottleneck for coral recruitment we compared the post-settlement survival of *A. palmata*, *A. cervicornis* and *F. fragum* on either *H. boergesenii* or *T. prototypum*. After six weeks in the field, *A. palmata* recruits had approximately 15 % survival on both *T. prototypum* and *H. boergesenii*, but *A.*





*cervicornis* recruits only survived on *T. prototypum* (13 %). None of the *Acropora* spp. recruits survived after a full year. After 6 weeks, *Favia fragum* recruits had 95% survival on both CCA species and after a year there was approximately 65% survival on *H. boergesenii* and 50%

## consequences: Social monogamy and sex allocation in a hermaphroditic shrimp from Carrie Bow, Belize

J. A. Baeza



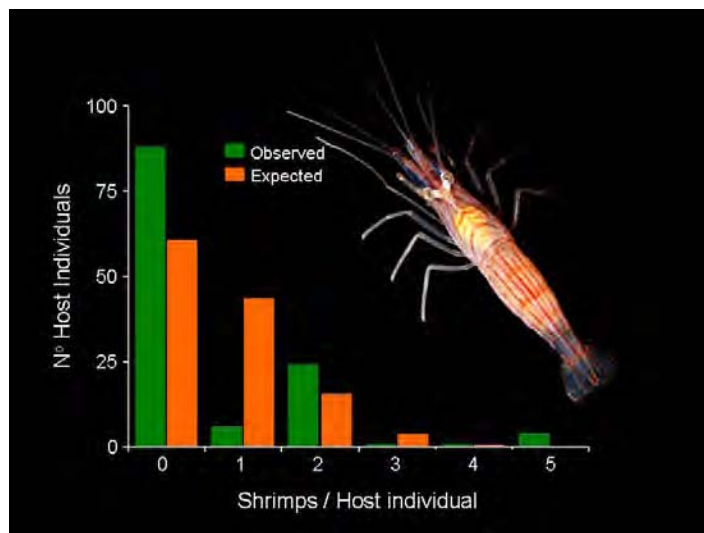
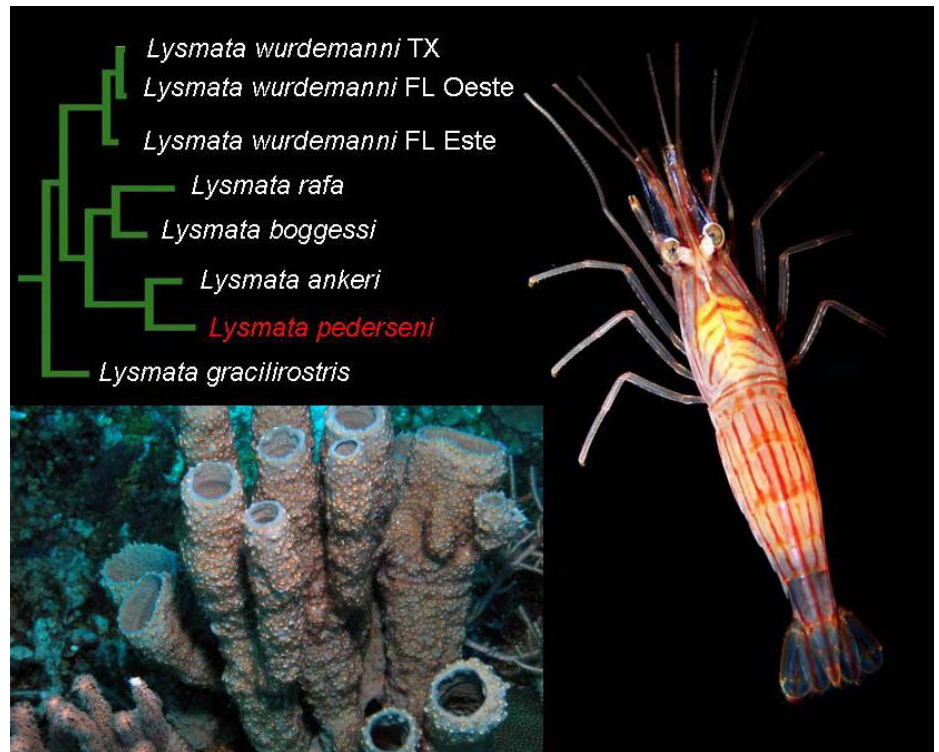
survival on *T. prototypum*.

## The symbiotic lifestyle and its evolutionary

Sex allocation theory predicts female biased sex allocation for simultaneous hermaphrodites with a monogamous mating system. Individuals are expected to produce the smallest amount of sperm necessary to fertilize their partner's eggs in the absence of sperm competition. In turn, mating systems theory predicts that monogamy is advantageous in environments where refuges are discrete, scarce, relatively small, and when predation risk is high outside of these refuges. In these circumstances, refuges should be monopolized by reproductive pairs because of refuge scarcity and high value for avoiding predation. These predictions were tested at Carrie Bow Cay, in the Caribbean marine shrimp *Lysmata pederseni*, a simultaneous hermaphrodite that lives inside tubes of the sponge *Xestospongia vaginalis* and which has an early (functional) male phase. The host sponge is a scarce resource that, together with the high predation risk typical of tropical subtidal environments, should favor monogamy in this shrimp. In turn, monogamy is expected to favor female biased sex allocation in hermaphroditic shrimp.

In agreement with the first prediction of this study, these shrimp were frequently encountered as pairs within these tube sponges at Carrie Bow Cay, Belize. Pairs were equally likely to comprise two hermaphrodites or one hermaphrodite and one male. Pairs of shrimp were found in the same host individual in-

dependent of their reproductive status or developmental stage of the brooded embryos. Body size of shrimp forming all-hermaphrodite pairs was strongly correlated. Several of these pairs were observed for long time intervals in the field (up to 54 days, including 6 or more female reproductive cycles). Lastly, laboratory experiments demonstrated that hermaphrodites tolerated other hermaphrodites but not males in “their” hosts. Together, these results suggest that pairs of hermaphroditic *L. pedersenii* are socially monogamous; they share the same host individual and reproduce exclusively for long periods of time. Nevertheless, males appeared less likely to establish long-term associations with others as indicated by the rate of their disappearance from their



hosts (greater than that of hermaphrodites). Supporting the second prediction, sex allocation was female biased in monogamous hermaphrodites. On average, hermaphrodites invested 40 times more to ova than sperm mass. Sex allocation was also size-dependent: female allocation increased more than proportionally with body size.

Social monogamy and female biased sex allocation are evolutionary consequences of adopting a symbiotic lifestyle in this and other species of simultaneous hermaphrodites. These findings support fundamental predictions of sexual systems and sex allocation theories and suggest that hermaphrodites are adopting mating decisions and adjusting reproductive investments to improve lifetime reproductive success.

## Environmental effects of density on sex allocation in a group-living simultaneous hermaphrodite: A contrast between geographical locations

M. K. Hart

My research examines variation in sex allocation and mating strategy for a simultaneous hermaphrodite in its natural environment. My study species is a group-living coral reef fish, chalk bass or *Serranus tortugarum*, found in aggregations numbering 20-500+ along reef slopes of sheltered mangrove islands, inhabiting substrate ranging from coral rubble to seagrass, sand or silt interspersed with patches of sponge and coral. This species spawns daily, pelagically and in pairs, with repeated reciprocation in gamete exchange by partners (termed egg parceling). Individuals also use an alternative male-role strategy termed “streaking” to gain extra fertilizations by intruding on neighboring pairs and releasing sperm as they are spawning. A comparative study I conducted at Bocas Research Station, STRI, Panama in 2005-2006, indicated that streaking and male (gonadal) allocation increase with density, both within study sites (among separate aggregations) and among study sites separated by several kilometers. The patterns found in Panama lend empirical support to long-standing theory on sex allocation and mating group



size in simultaneous hermaphrodites. In 2007-08, I began to add study sites near Carrie Bow Cay in Belize to determine whether density-related sex allocation patterns prevailed at a different geographical location.

Near Carrie Bow Marine Lab, chalk bass are found along a seagrass-coral rubble mixed slope along southeast Wee Wee Cay and along the steep slopes of the mangrove islands of the Pelican Cays where, in October 2008, I established five study sites, measured density, and collected fish to examine gonadal allocation ( $n=45-78$  from each site). In chalk bass ovarian and testicular tissue are clearly distinguishable; all gonad samples will be separated under a microscope, dried and weighed for a proxy of proportional sex allocation (i.e., male allocation equals the proportion of total gonad made up of testicular tissue). The otoliths were extracted and stored and will be used to compare longevity and growth rate in Belize populations with those from Panama. I have begun to process gonad samples with the aid of an undergraduate from University of Kentucky, Megan Clauson, who is interested in gaining research experience.

Preliminary data for male allocation and body size (i.e., soma mass) from three study sites ( $n=15$  each for Little Cat Cay, Avicennia Cay, and Wee wee Cay) were contrasted with the Panama average. The generally lower male allocation and larger body size in Belize populations indicate a potentially strong influence of geographical location on mating strategy. These differences may result from differ-

ences in environmental factors such as resource availability or predators that influence growth, survival, and, ultimately, size and reproductive allocation patterns.

Preliminary results raise questions about whether density has the same positive effects on male allocation in Belize as it does in Panama, as indicated by the variable patterns among study sites that are not clearly related to density. In Belize, local differences in body size and reproductive investments patterns may have more influence than density on sex allocation. The addition of study sites near Carrie Bow Cay adds a dimension to my research that gives insight into potential interactions between environment, life history, and behavior; this study has important implications for fully understanding how environment shapes sex allocation patterns.



# Ecology, Population Dynamics, and Ecophysiology

## Environmental regimes dictate isotopic signatures, iron assimilation and biomass accumulation in *Lyngbya polychroa*

K. Semon

My research with the Smithsonian Marine Science Network system has focused on understanding trends and factors influencing blooms of the filamentous cyanobacteria *Lyngbya* spp. This year, I continued to sample *Lyngbya* spp. tissue for stable isotope analyses of nitrogen and carbon in order to identify potential source waters (i.e., treated sewage, land-based waters flowing out from canals and inlets, or natural water recycling) carrying the nutrients that may fuel cyanobacteria blooms. I conducted a nutrient bioassay in Belize comparing the iron affinity of *Lyngbya polychroa* from a mangrove system (Twin Cays) and from the forereef system of Carrie Bow Cay.

*Lyngbya* spp. collected from the reef tract and from the Twin Cays mangroves display markedly different isotopic signatures ( $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ). *Lyngbya* tissue samples from the mangroves were isotopically heavy in  $\delta^{13}\text{C}$  (relative to reef-based *Lyngbya*), and reflective of mangrove signatures. These discrepancies indicate that either *Lyngbya* can cue in on a suite of source waters (based on the range of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  signatures analyzed from many tissue samples), or may switch its acquisition pathways in order to opportunistically accommodate the nitrogen and carbon available. Bioassays conducted in Belize suggested that *Lyngbya polychroa* collected from the Carrie Bow reef may be more iron-limited as it grew at a faster rate than *Lyngbya polychroa* collected from the Twin Cays mangroves. Both the isotopic signatures and the potential difference in iron affinity suggest that *Lyngbya* is highly adaptable and opportunistic, once established, may be capable of persisting through a range of nutrient regimes and

physical conditions across a range of habitats. Point and non-point source pollution from land do not appear to be the only nutrient source fueling *Lyngbya* blooms.

## Qualitative assessment of seagrass habitats

J. Douglass

In October, 2008 I traveled to the Carrie Bow Cay research station to begin some of my tropical seagrass community sampling and to assist other Smithsonian researchers with unrelated projects. My specific goals were: 1) to make a qualitative assessment



of seagrass habitat variation around Carrie Bow Caye and Pelican Cayes, 2) to adapt my quantitative assessment methods, developed in eutrophic estuarine seagrass beds, to sampling in oligotrophic *Thalassia testudinum* beds, and 3) to make epifaunal grab sample comparisons of seagrass-associated communities across the range of physical environments in which *Thalassia testudinum* is

found in the area. The five areas from which I took grab samples are described in the table below.

Having assessed the variation in community composition among these different types of *Thalassia* habitat, I will be better able to judge whether community differences I see in future surveys of marine reserves versus non-reserve areas are due to real reserve effects, or merely to local-scale, habitat-type differences. (The Belizean marine reserve I plan to do the comparison around is Laughing Bird Caye, near Placencia).

## Temporal changes in invertebrate abundance and diversity associated with seagrasses at Carrie Bow Cay, Belize

M. Mach & R. I. Eytan

Globally, marine ecosystems have been subjected to various human disturbances including over fishing, coastal development and polluted runoff. These stres-



sors are known to reduce coastal biodiversity. Regions like the Belizean barrier reef have suffered anthropogenic and natural disturbances, such as hurricanes and erosion, but the effects of these disturbances are poorly understood. We sought to test the hypothesis that thirty years of disturbance to Belizean reefs reduced the local diversity and abundance of species.

Young and Young (1982) studied the invertebrate communities associated with seagrasses and bare sand patches at Carrie Bow Cay, Belize in 1976. We replicated their methods 32 years later, using sediment cores to sample infaunal invertebrates in and near *Thalassia testudinum* seagrass beds. Concurrently, we also measured environmental data on sediment size, water quality and seagrass density to compare current patterns in species abundance and diversity to biotic and abiotic conditions in and near the seagrass beds.

Preliminary results indicate that species richness is currently lower and invertebrates are 90% less abundant than in 1976. Future non-metric multidimensional scaling analyses will compare overall community composition in *Thalassia* beds and bare sand patches between 1976 and 2008.

## Mangrove transcriptomics and the effects of nutrient supply on transcript profiles in *Rhizophora mangle*

J. Cheeseman

While the greatest part of the attention to mangroves within CCRE is, appropriately, to their ecology and ecophysiology, the goal of this project is to extend our understanding of the mangrove extremophile lifestyle to the molecular level. In this way, we expect to be able to exploit the trees mechanisms of adaptation to extreme environments with-



out destroying either trees or habitat. Two primary targets of that exploitation are (1) understanding of genes (and their control) that could be transferred to model or crop plants, and (2) understanding underlying molecular characteristics that could be referenced in mangrove restoration efforts.

This year, we completed the first transcriptome analysis using pyrosequencing techniques for any plant for which no prior genomic information was available. We selected *R. mangle* and *Heritiera littoralis* (an old world mangrove) as ecologically important species employing markedly different physiological and life history strategies for survival and dominance in their ecosystems. For maximal representation of conditional transcripts, mRNA was obtained from a wide variety of developmental stages, tissue types and habitats, including both fringe and stunted, unfertilized, P-supplemented, pioneer and bird-fertilized trees. Normalized cDNA libraries of pooled mRNAs were analyzed using Roche/454 pyrosequencing.

A total of more than 500,000 sequences were assembled de novo (the first time this has been accomplished with any species in the absence of a template genome) and annotated as >10,000 distinct gene



models. Gene ontology (GO) and KEGG orthology annotations highlighted remarkable similarities in the mangrove transcriptome profiles, both of which differed substantially from model plants. The similarities suggest a unique mangrove lifestyle overarching the effects of transcriptome size, habitat, biogeographic and phylogenetic differences between them.

Following up this study, we have collected additional tissue samples from roots and shoots of unfertilized and P-supplemented *R. mangle* from the dwarf zone, and from naturally fertilized plants at Man-o-War Cay. These samples are currently being sequenced using an Illumina/Solexa instrument. The result will be approximately 20 million, 76 bp sequences. The sequencing has two objectives. First, again using normalized libraries, we will fill in gaps in the transcriptome, increasing coverage from ca. 40% to nearly 100%. This will allow follow up studies using quantitative PCR techniques to examine the effects of environmental conditions on the expression of individual genes. Second, using non-normalized libraries, we will quantitatively compare gene expression in unfertilized, P-fertilized and bird-fertilized roots and shoots to identify responses to nutrient conditions.

Propagules collected from a single tree at Twin Cays are also being grown under greenhouse conditions with varying levels of salinity and N/P fertilization to quantitatively examine transcriptome differences in developing seedlings.

### ***Mangrove conservation workshop***

In June, the Department for International Development (Belize), WWF and the Southern Environmental Association (SEA, formerly Friends of Nature) held a mangrove conser-

vation workshop at the Placencia Community Center that was attended by approximately 30 people from the

community and from as far away as Dangriga (Gra Gra Lagoon National Park). The workshop included talks on climate change effects, disaster preparedness and mangroves, a timeline of mangrove removal in Belize, mangrove conservation in Placencia, and a hands on mangrove planting practicum at a resort under construction.

I was asked to participate and talk about the biology of mangroves and biological factors involved in their restoration (mangrove life histories and problems of shoreline protection), calling heavily on experiences at Twin Cays and Carrie Bow. I also met (both in September and June) with the manager of the Aqua Mar shrimp farm who has been very cooperative with SEA in establishing mangroves as a means of effluent treatment. We discussed the results of planting efforts, the nutrient monitoring and amelioration experiments she is allowing NGOs and high school students from the US to conduct, and I encouraged the efforts she and SEA are making to protect existing trees and extend/rehabilitate mangrove and sea grass habitat.

### **Community dynamics on mangrove roots**

*J. Wulff*

Aiming to understand community dynamics on mangrove prop roots, I have fully censused sponges on the same set of mangrove roots or root clusters at Hidden Creek and Sponge Haven for 3 years (i.e., 4 censuses). Because the data were collected by following every individual sponge through time, they simultaneously provide information on community dynamics and life histories





of individual species. Sponge species exhibited very similar survival patterns at these two sites and also at a third site in Bocas del Toro, Panama; and their population dynamics suggest that each species is especially suited to a particular time period in community development. The field work for this part of the project is completed, and the analyzed and interpreted data are in press in a paper entitled "Sponge community dynamics on Caribbean mangrove roots: significance of species idiosyncrasies" in Smithsonian Contributions to the Marine Sciences.

Community assembly from the beginning (i.e., bare substratum) can be studied by following settlement, and subsequent growth, interactions, and mortality on PVC pipes suspended among the mangrove roots. For over 5 years I've been tracking the changes in species composition, diversity, cover, etc. on initially bare pipes. In the lower diversity site, Hidden Creek, community assembly appears to be more deterministic than it is at the higher diversity Sponge Haven site; and after only three years the suspended pipes at Hidden Creek were indistinguishable from adjacent mangrove roots, with the majority of them dominated by the most abundant (by volume) sponge species in this community, *Tedania ignis*. In combination with the repeated census data, this recruitment and community assembly portion of the study can help 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?***

In a grand reciprocal transplant study, involving dozens of sponge species that are typical of mangroves, seagrass meadows, or coral reefs, I have been comparing growth and survival of each species in each habitat, hoping to determine what factors really control habitat distribution of these common species. All pair-wise reciprocal transplants between mangroves, seagrass meadows, and reefs have been underway for 1-3 years. One of the striking results from the experiments is that some of the typical reef and seagrass sponge species tend to grow very much more rapidly in the mangroves than in their usual habitats. Ecological interactions may inhibit sponges from living in the habitats that are most favorable with respect to food availability and abiotic factors.

### **Species composition of scleractinian coral life and death assemblages**

*K. Cramer & C. Angioletti*



We originally intended to collect two types of data during our time at Carrie Bow: (1) the species composition of scleractinian coral life and death assemblages from line transect surveys and (2) sediment samples from each line transect survey

for microfossil and percent carbonate analyses. This data was to be collected in order to determine the extent of change in coral communities and in reef water quality over the past decades, using changes in sediment and foraminifera community composition as indicators of influence from land runoff.

Because of the thick macroalgal growth on many of the coral skeletons, it was not feasible to reliably identify coral death assemblages in situ. We therefore decided to focus our efforts on collecting sediment

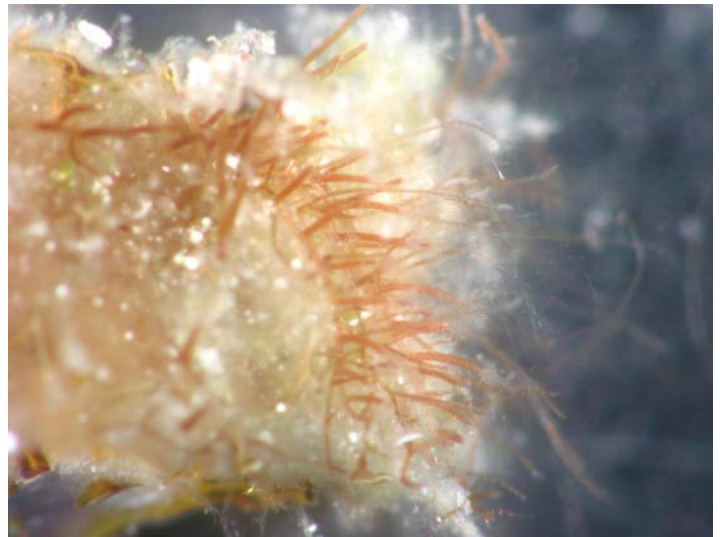
cores only. Using SCUBA, three 0.5-m long cores were taken at 5m water depth at five reefs sites: two rhomboid shoals representing lagoonal environments, two patch reefs just inside the barrier reef representing moderately exposed environments, and one barrier reef off Carrie Bow representing an oceanic reef environment. Cores were frozen and then extruded at 2mm increments and placed in baggies to be dried and analyzed in the lab at my home institution. Percent carbonate and percent symbiotic versus heterotrophic benthic foraminifera in each sediment layer will be determined to indicate relative measures of land-based sediments and water clarity. These analyses will be completed by mid-2010.

## *Aplysina* red band syndrome at Carrie Bow Cay, Belize

*K. Ruetzler, M. C. Diaz, D. G. Gochfeld, J. B. Olson, C. Piantoni, R. W. Thacker, & E. Villamizar*

*Aplysina* Red Band Syndrome (ARBS) is an emerging infectious disease of Caribbean marine sponges of the genus *Aplysina* (Aplysinidae, Verongida). First described in the Bahamas in 2004, this disease is now believed to be widespread throughout the Caribbean. The goal of this study was to survey habitats of the Mesoamerican Barrier Reef near Carrie Bow Cay, Belize, for the presence and abundance of ARBS and to assess the relationships between disease and biodiversity and species composition of coral reef communities.

Analyses suggest that ARBS prevalence was not correlated with sponge, coral or gorgonian diversity. Mats of red filamentous cyanobacteria were observed on corals, gorgonians, sponges (including *Aplysina* spp.) and abiotic substrata, but their abundance



was not correlated with ARBS abundance. We repeated our surveys in 2009, and found a small but significant increase in sponge species diversity and abundance on these patchreefs, along with a 33% increase in ARBS prevalence.

We labeled and measured each ARBS-affected *Aplysina cauliformis* along our transects, as well as its nearest healthy neighbor. In 2008, we marked a total of 18 pairs of sponges by attaching numbered plastic tags with cable ties at their bases. For diseased sponges, we measured the length of healthy tissue from the cable tie to the lower end of the band, the widths of the lower band, the lesion and the upper band, and then the distance to the tip of the branch. For healthy sponges, we measured total length from the cable tie. We also measured the distances to nearest healthy and diseased neighbors and recorded the number of sponges within a 1 m radius that were healthy, or had ARBS, or other lesions. These marked sponges were relocated in 2009 and remeasured. This analysis demonstrated a significant cost of ARBS infection to the host sponge. Healthy sponges grew 35.5% in one year, whereas ARBS-af-

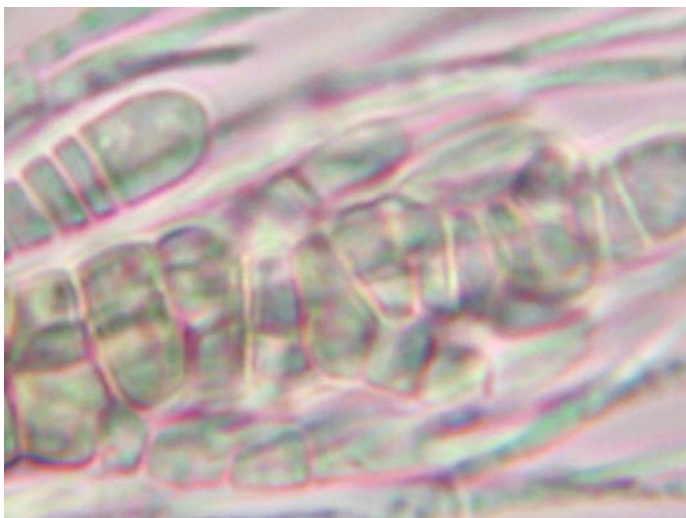




fectured sponges decreased in length by 22.3%. Only one of our marked diseased sponges still had an active ARBS band in 2009, however, suggesting that ARBS lesions may senesce or even heal after several months.

During an unrelated survey, one of us (C. P.) observed and collected a partially diseased specimen of *Niphates digitalis* (Niphatidae, Haplosclerida) on the Carrie Bow fore-reef. No red band was seen on this species but an infection was apparently in progress, indicated by a rotted patch surrounded by healthy tissue. We hope to identify a pathogen by sampling and fixing, for microscopy, the healthy, diseased, and transition zones.

Subsamples were fixed in the field for later microscope study at Natural History Museum facilities. Scanning (SEM) and transmission (TEM) electron photomicrographs of healthy and infected *Aplysina cauliformis* and *Niphates digitalis* sponges were prepared for comparative analyses. *Aplysina* contained unicellular prokaryotic symbionts (free in the mesohyle, inside bacteriocytes, and some being engulfed by sponge cells), with *Beggiatoa* and other sulfur-fixing bacteria inhabiting diseased areas. The associated “disease community” (saprophages) consists of coccoid, rod-shaped, and filamentous (*Leucothrix*-type) bacteria, diatoms, filamentous red algae (*Polysiphonia* sp.), ciliates, polychaetes, and amphipods. In the diseased zone, choanocyte chambers disappear (choanocytes are no longer recognizable) and there are many signs of sponge cytolysis. There is no indication that the symbiotic microorgan-



isms turned against their host, as was shown in a previous study of a mangrove sponge (*Geodia*) during a period of thermal stress. In *Niphates*, in not-yet-decaying tissue (but neighboring infected zones), we found characteristic filamentous cyanobacteria. Although we have no experimental evidence that this organism is the disease agent for *Niph-*

*ates*, it certainly is not a symbiont in healthy *Niphates*.

Preliminary results from this study suggest that while ARBS prevalence on the Belizean barrier reef near Carrie Bow Cay is currently less than what has been observed on patch reefs at similar depths in the Bahamas, this and other sponge diseases seem to be increasing in abundance. ARBS-affected sponges display significantly less growth than healthy *Aplysina* specimens, indicating that this condition has

serious consequences, not only for the individuals but also for the productivity of the population and the entire community. Broader studies of pathogens and factors affecting the incidence of ARBS and other sponge diseases on the Mesoamerican barrier reef as well as elsewhere in the Caribbean are clearly needed.

## Snapping shrimp (*Synalpheus*) sponge host-use biogeography

K. Hultgren & T. Macdonald

Sponge-dwelling *Synalpheus* snapping shrimps are one of the most diverse groups of Caribbean coral-reef invertebrates, and the majority of the pioneering work on this genus has been conducted over the last ~20 years at Carrie Bow Cay, by Dr. Emmett Duffy

(and various collaborators). These data have led to a number of intriguing hypotheses about how sponge host use influences community assembly and speciation in *Synalpheus*, which Dr. Duffy and I have been testing over the last years through a series of field trips to four additional Caribbean locations (Barbados, Curacao, Jamaica, and Panama). During these trips, we have focused specifically on how sponge characteristics (e.g., volume and canal size) influence *Synalpheus* inhabitants. The purpose of my recent expedition to Carrie Bow Cay (with Dr. Tripp Macdonald) was to collect the same type of data on sponges from Belize, to complement similar measurements taken elsewhere in the Caribbean and to be able to more accurately compare and contrast sponge hosts among multiple locations.

During our week at CBC, we collected 84 sponge hosts and measured sponge volume and canal size by sectioning and photographing sponges. We were able to collect ~95% of the entire sponge host species of *Synalpheus* recorded over the last two decades, and took extensive photo and tissue vouchers of these hosts. We also plan to describe three to four additional *Synalpheus* species, based on our collections during this expedition and on previous collections.

## Community consequences of predation: A latitudinal perspective

### A. Freestone

Species interactions are assumed to be stronger at lower latitudes, but surprisingly few experimental studies test this assumption, and none tie fundamental processes such as predation to patterns of species diversity across latitude. In collaboration with Richard Osman (SERC), Gregory Ruiz (SERC), and Mark Torchin (STRI), I conducted a large-scale predator exclusion experiment on sessile marine invertebrate communities in four regions across 32° latitude in the western Atlantic Ocean and Caribbean Sea, specifically Long Island Sound in Connecticut, Indian River Lagoon in



Florida (SMSFP), vicinity of Carrie Bow Cay (Carrie Bow and Twin Cays) in Belize, and Bocas del Toro in Panama (STRI). Experimental habitats (100cm<sup>2</sup> PVC panels) were deployed in shallow seagrass beds for three months with five treatments that manipulated predation pressure (predator exclusions and controls). Deployments in the temperate zone coincided with the very predictable season of recruitment and growth in the late summer. In the tropics, where recruitment and growth occur year-round, iterative

deployments were conducted. Belize deployments were as follows: April-July 2008, July-October 2008, and October 2008-January 2009. To further test for effects of predation on more established communities, three-month-old communities that had developed in the absence of predation were then exposed to predation for seven days in January, 2009.

The effect of predation on community diversity was strong and consistent in the tropics, while no effect on species diversity was observed in the temperate zone. For the three-month experiments in Belize, predation was strongest during the first and third deployments, with predator exclusion communities harboring significantly more species than control communities that were exposed to predation. Predation pressure appeared to be somewhat weaker during the height of the rainy season, a pattern that was also observed in Panama. However, in Belize overall, communities that developed in the absence of predators were 1.5 to 3.5 times more diverse than communities that developed in the presence of predators. When diverse communities in Belize were then exposed to predation for seven days, species losses were substantial and ranged from 21% at Twin Cays to 35% at Carrie Bow. In contrast, while taxonomic shifts among treatments were observed in the temperate zone, predation had no effect on species diversity patterns. These results are consistent with the long-held prediction that predation pressure is stronger at lower latitudes than higher latitudes and is an important driver of species diversity patterns in the tropics.



# Species Interaction and Behavior

## Coral-algal-microbial interactions on reefs of Belize

V. J. Paul, K. Morrow, C. Ross, & R. Ritson-Williams

Experiments were conducted with live algae and algal extracts in Belize in August 2009 to assess whether common macroalgae negatively impact coral health through chemical and/or physical competition. Non-polar extracts (extracted with the solvents ethyl acetate:methanol 1:1) of common macroalgae were prepared at the Smithsonian Marine Station in Fort Pierce and were transported to Belize. Five individual corals of *Montastraea faveolata* and *Porites as-*

*treoides* were treated by placing the extracts incorporated into a phytagel matrix onto the surface of the coral colony. Live algae and extracts from three algal species commonly found in Belize were tested; *Lobophora variegata*, *Halimeda tuna*, and *Dictyota* sp. Each individual coral tested had three mucus samples taken before the experiment to determine the baseline coral microbial community. Live algae and extracts with their appropriate controls (5 replicates of each) were placed on the coral colonies and left for 3 days. At the conclusion of the experiment mucus from all of the coral colonies was sampled for microbial community analysis and a small piece of tissue was removed for stress enzyme analysis. Coral mucus samples were con-

centrated via centrifugation, the supernatant removed, and immediately frozen to preserve coral-associated microbes. Coral tissue samples were flash frozen in liquid nitrogen to preserve the enzymes for quantification in the laboratory. The mucus samples will be processed at Auburn University using molecular profiling techniques (e.g. ARISA, DGGE) to investigate the effect of experimental treatments on in situ coral-associated microorganisms. At the University of North Florida the

coral tissue samples will be evaluated by a suite of commercially available biochemical assays or cellular diagnostic kits, including lipid hydroperoxide assay, protein carbonylation assay, catalase and superoxide dismutase activity, all of which give information on the levels of oxidative stress and protein metabolic condition in corals exposed to the different macroalgae and algal natural product treatments.

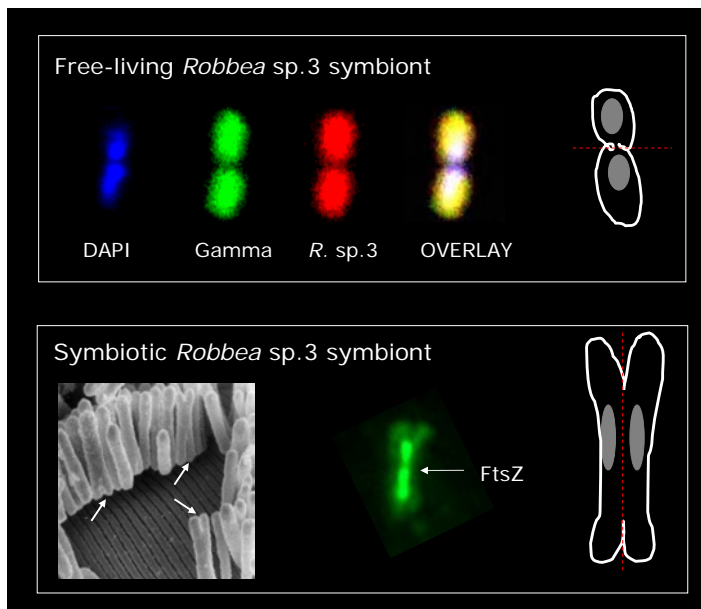




# Molecular mechanisms of establishment and maintenance of a nematode/bacteria symbiosis

## *S. Bulgheresi*

Stilbonematids are marine nematodes that establish highly specific ectosymbioses with chemotrophic sulfur-oxidizing Gammaproteobacteria. They thrive a few centimetres below the sea bottom, where their migrations between superficial and deep sand allow the bacteria to alternatively obtain oxygen and sulfide. In turn, the symbionts are the major components of their host diet. The stilbonematid *Robbea* sp.3 inhabits the shallow water off Carrie Bow Cay and is covered by a monolayer of rods. These symbionts display a striking metabolic and cytological flexibility. Fluorescence In Situ Hybridization revealed indeed that their planktonic, free-living counterparts may survive in off-shore superficial seawater. Surprisingly, the latter divide by transversal binary fission, whereas the *Robbea* sp.3-associated bacteria set their division plan longitudinally.



On my 2009 visit to Carrie Bow Cay I mainly collected *Robbea* sp.3 nematodes to investigate the molecular basis of this outstanding cytoengineering feat which would ensure proliferating symbionts to stay attached to the host's surface. Our working hypothesis is that the longitudinal fission results from a 90° shift in the localization of the MinCDE proteins, a machinery which inhibits the formation of the contractile ring in *E. coli*. In this well studied system, on time average, the inhibitors' complex is maximally concentrated at the

poles and minimally at mid-cell. Therefore, the contractile ring, a polymer of the tubulin homologue FtsZ, is set at mid-cell and divides the cell into two equal halves. We immunostained the *Robbea* symbionts with antibodies against *E. coli* FtsZ, MinC and MinD. As expected, MinC and D appeared to accumulate on the lateral sides of the symbiont, rather than to the poles, allowing the formation of a contractile ring aligned to the bacterial long axis. Moreover, two MinCD-rich regions appear to direct the site where the furrow starts to ingress, namely at the bacterial pole in contact with the cuticle. We are now analyzing MinE localization pattern, cloning the *Robbea* minCDE genes and trying to identify if host-secreted factors can induce the longitudinal fission in the free-living counterparts of the *Robbea* symbionts.

Finally, during my 2009 stay, I could artificially induce egg laying in our model stilbonematid *Laxus oneistus* by soaking it in high concentrations of cytochrome C oxidase double strand or anti-sense RNA. PCR with primers against eubacterial 16S rDNA confirmed the microscopic observation that early embryos are symbiont-free. This supports environmental acquisition of the symbionts by freshly hatched nematodes.

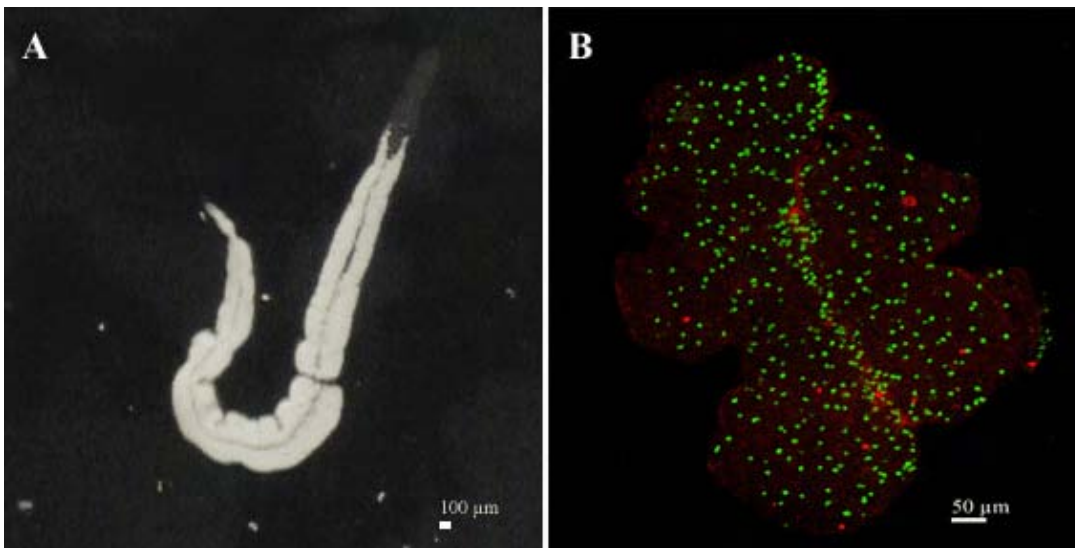
## Symbiont transmission and reproduction in marine flatworms with chemoautotrophic microbial symbionts

*J. Ott & U. Dirk*

Flatworms of the genus *Paracatenula* Sterrer and Rieger 1974 (Catenulida, Platyhelminthes) are part of the interstitial meiofauna at the oxic-anoxic interface in shallow water subtidal sands of tropical to warm temperate oceans. Adult *Paracatenula* lack a mouth and a gut lumen. Instead, a parenchymatic "trophosome" containing intracellular bacteria fills most of the body. Based on the results from extensive sampling on the *Paracatenula* diversity in the vicinity of Carrie Bow Cay field station by Jörg Ott and Harald Gruber in the year 2008, we were now able to collect large amounts of selected species we want to study in more detail. The three *Paracatenula* species we have chosen for more detailed studies are *P. erato*, *P. sp.2* and *P. sp.3*.

Flatworms are characterized by an outstanding stem cell system. These stem cells (the neoblasts) can give rise to all cell types including the germ line for the whole lifespan. Additionally they are the key compo-





Indications for asexual reproduction: (A) *P. erato* with a clear fission plane (red arrow) (B) Antibody staining of neoblasts stem cell distribution in the posterior body region of *P. erato* (s-phase neoblasts green, mitotic neoblasts red)

nent of the exceptional regenerative capacity of many flatworm species. Because neoblasts are the only dividing cells in flatworms, they can be specifically labelled by BrdU (Bromodesoxyuridin) incorporation. Afterwards this label can be shown with an antibody against the BrdU label. Positive BrdU incorporation indicates that the cell was in the S-phase of the cell cycle during the incubation. Also mitotic neoblasts can be shown with an antibody against phosphor-histone 3.

During our stay on Carrie Bow Cay we incubated different species of *Paracatenula* for different time periods in BrdU before they were fixed in formaldehyde. In the Lab in Vienna these animals were further analyzed and gave us first insights into the *Paracatenula* stem cell system. Like in all other flatworm groups *Paracatenula* has no mitotic and no S-phase neoblasts in the most anterior body region, the rostrum. The neoblasts are restricted to the posterior body region and are randomly distributed. The symbionts of *Paracatenula* are living inside specialized cells of the worm, the symbiocytes. A more specific question we address is the origin of these symbiont harbouring cells. Therefore we permanently labelled S-phase and mitotic neoblasts with HRPtyramide deposition and subsequently made cross sections, which should allow to assess whether the symbiocytes undergo mitosis or S-phase inside the trophosome. These results additionally can show us if there is a transmission of symbionts between cells. The transmission is one of the key mechanisms for the maintenance of the symbiosis along the ontogenic as well as the phylogenetic development.

## Development and reproduction in the genus *Paracatenula*

Since the first description of the genus *Paracatenula* in 1974 it is hypothesized that there is a sexual reproduction within the genus. Sterrer and Rieger (1974) described structures in some specimens that they speculated to be sperms. Although we could observe neither such structures nor sexual reproduction, we are aware that some flatworms are known to switch between asexual and sexual

reproduction within one life cycle. It is possible that *Paracatenula* reproduces sexually only rarely. In contrast we found strong indications for an asexual mode of reproduction like it has been described for other flatworms especially some catenulids. Fission planes like this have been described for other asexual reproducing flatworms like *Microstomum* sp. A second indication for asexual reproduction in *Paracatenula* is the stem cell distribution. Previous studies on the stem cell distribution patterns in flatworms have shown two general patterns: (1) in species that reproduce exclusively sexual the stem cells are restricted to specific body regions. This is for example the case for *Macrostomum lignano* where the S-phase neoblasts are distributed in two bands along the lateral sides of the organism. (2) Species that do reproduce asexual either occasionally or exclusively, the stem cells are randomly distributed. Thus the random neoblast distribution we find in *Paracatenula* supports the hypothesis for the mode of asexual reproduction within the genus *Paracatenula*.

## Associations and overgrowth of octocorals by sponges

*E. L. McLean*

Associations and overgrowth of some octocorals by some rope-like sponges were studied looking at different species-pairings and their natural occurrence in two different habitats. The two chosen study sites consisted of a spur and grove zone on the front eastern side



of Carrie Bow Cay (35 feet deep), and a patch reef 1.5m south of Carrie Bow Cay along the channel (28feet deep). Both sites have a good representation of corals and octocoral, with the latter site having a higher sponge density and therefore a higher incidence of octocoral-sponge associations.

In light of previous findings, a host-parasite framework is considered in order to determine the applicability of this model and the implications for these important dynamic interactions. Under this paradigm, I looked at how the association/infection begins (attachment), how it affects the octocoral colony (host), whether it can recover once the sponge (parasite) is removed. I hypothesized that the prevalence and intensity of the infections is influenced by host specificity (species pairings) as well as by the habitat conditioning that account for the presence of one and the other.

The initial field work (July 9-29th, 2009) consisted of both census and experiments to assess both process and patterns. The experiments consisted of attaching live fragments of sponges on live octocoral colonies along two transects. The first experiment looked at naturally-occurring sponges that overgrow octocorals, testing for time (days) of attachment under two circumstances: (1) attachment on live octocoral tissue, and (2) attachment on bare octocoral axis [complimentary to this experiment, observations were done in the wet lab facilities to observe closer the attachment preference of lives vs. bare octocoral axis]. A second experiment assessed the ability of the same sponges (from the first experiment) to attach and grow on octocorals on which they do not co-occur, and the



third experiment looked at sponges that do not overgrow octocorals, testing them on the same octocorals from the first experiment. Assessment of the effects of the species-pairings varied from no effect, to mild effect, to octocoral tissue damage and, in some cases, overgrowth within 5-9 days. The results on the speed of attachment and overgrowth varied in func-



tion of the species involved. For the species pairings that do not occur (experiment 2 and 3) no real attach-



ment took place, but a remarkable avoidance/resistance effect was seen on the octocoral with a marked swelling of the tissue that was in contact with the sponge.

Census along belt transects (10 x 1m) at each of the study sites were done recording all octocorals present (identified and measured) and the number of associations (prevalence) consisting of overgrowing (rope-like) sponges on the octocorals, as well as the intensity (percentage of axis covered) of the associations. Furthermore, coral cover assessment was done using snapshot photograph methods. An initial assessment of sediment dynamics indicated that the quantity of the small fraction sediments is three times higher in the patch reef site than in the spur and grove site. After completing the experiments and the abundance and distribution census, a number of species pairing samples from experiment 1 were photographed and measured in order to monitor for sponge growth after 5-6 months. Lastly, a number of naturally occurring octocoral-sponge associations were selected on a third transect and their associated sponge was completely removed in order to monitor for octocoral tissue recovery after 5-6 months.

By seeking to quantify the cost and benefits for the octocoral and sponge respectively, I seek to determine if these associations are likened to a parasitic association, or perhaps a structural parasite, similar to lianas that topple on the canopies of trees. So far, overgrown octocoral colonies are unable to overgrow their associated sponges, meaning that the sponges are favored by a higher competitive ability, but if these sponges have more to gain from the association, then perhaps they should favor a lower 'virulence' that would benefit them in the long run.



*Rocinela signata* attached in the lower anterior gill chamber of the Bluestriped Grunt, *Haemulon sciurus* at Carrie Bow Cay.

## Consistent attachment by the monogram isopod, *Rocinela signata* (Isopoda: Aegidae) on the bluestriped grunt, *Haemulon sciurus* at Carrie Bow Cay, Belize and a host list

E. H. Williams, Jr., L. Bunkley-Williams, & M. J. Dowgiallo

This rather small isopod (up to 15 mm long) is the only one in the western Atlantic considered to be dangerous to humans. It was originally found on either a grunt (*Haemulon*) or a drum (*Sciaena*) from the West Indies. It has since been found on a great variety of fishes.

We called *R. signata* the "Monogram Isopod" because of the obvious M-shaped marking on its tail (pleotelson). Of course, this could represent an inverted "W."

This isopod attaches to fishes, usually in their gill chambers, and feeds off their blood. The black material in the specimen is fish blood in the stomach of the isopod. It prefers larger fishes, particularly hogfish, groupers, and snappers, and may cause considerable economic loss by slowing the growth of these commercially important fishes.

*Rocinela signata* appears to have no host specificity. The preference for larger fishes may just represent habitat preference in a relatively safe and nutrient-rich environment.

This isopod spends much, if not most of its time in the substratum off any host. It is a temporary parasite or selective predator. Gravid females do not feed, and therefore, are never found attached to a host.

This is the only isopod of which we are aware that routinely attacks humans. In the few cases of bites in which we were able to obtain, all were *R. signata*. We have not witnessed the mass attacks reported off Colombia, but we have no doubt that this pest would be capable of such attacks. A single bite is painful, but not dangerous. Blood flow from the wound after an attack can be unnerving to a diver.

The known geographic range of this isopod includes the east coast of the USA from North Carolina through Florida, the Gulf of Mexico, the West Indies, and the Atlantic coast of South America through mid Brazil (~34.5°N to ~5°S). The isopod may not occur in extreme northern Gulf of Mexico. It has been found from the shallows to at least 100 m.

We found *R. signata* consistently attaching in the lower anterior gill chamber of the Bluestriped Grunt, *Haemulon sciurus* at Carrie Bow Cay. This species has never been reported to show any consistency in its attachment position or any host specificity. This odd situation requires more study to determine its significance.

*Rocinela aries* Schiödte and Meinert, 1879, from the Eastern Pacific, has been synonymized with *R. signata*. Although these forms are very similar and possibly “sister species,” we believe that the two species are distinct. *Rocinela aries* also associates with fishes and has a monogram mark on its tail like *R. signata*.

The mark is more diffuse on *R. aries* than on *R. signata*; however, we found some specimens of *R. signata* with diffuse marks in the Caribbean off Colombia.

Samples from Carrie Bow Cay and Bocas del Toro Marine Laboratory could genetically resolve this question.

## Processes across Ecosystems

Latitudinal variations in ecological stoichiometry in mangrove communities: What is the impact of nutrient loading on canopy and benthic food webs?

I. C. Feller & C. E. Lovelock

Mangroves form complex marine ecosystems with spatial differences in structural complexity, biodiversity, biogeochemistry, and hydrology that vary at local and regional scales. Although mangroves provide critical ecosystem goods and services, they are threatened globally by changes in climate and nutrient over-enrichment of the coastal zone. Using latitude and tidal elevation as proxies for climate change and sea level rise, our goal is to determine how excess nutrients interact with these components of global change to alter community structure, food webs, and patterns of herbivory in mangrove ecosystems.

We used a series of long-term fertilization experiments across ~2185 km and 18° of latitude that have been maintained at three locations along the Atlantic coast (Indian River Lagoon, Florida; Twin Cays, Belize; Bocas del Toro, Panama). At each locations, red mangrove (*Rhizophora mangle*) trees are fertilized with one of three nutrient enrichment treatments (control, +nitrogen, +phosphorus) in two tidal elevations (fringe, scrub) along transects perpendicular to shorelines. We determined the abundance of the primary consumers at each fertilized tree and measured herbivory as a function of folivory, loss of yield, and tissue mining. To characterize food webs and elemental stoichiometry of individual organisms, we also sampled marine, benthic, and terrestrial communities at each of the fertilized trees. Sampling is still under way. Elemental and isotope analyses will be conducted when





field sampling has been completed.

We have shown in previous studies that all sites were nutrient limited, but patterns of nutrient limitation varied by zone and latitude. Nutrient enrichment had dramatic effects on herbivory that varied by treatment, tidal elevation, latitude, and species. Responses to eutrophication of mangrove ecosystems will depend on site characteristics, the species considered, and the nature of nutrient limitation. Predicting how food webs will respond to nutrient over-enrichment requires an assessment of spatial heterogeneity coupled with feeding strategies and species-specific behavior, measured on multiple scales of response.

## Pulsed boundary layer flow versus tide-driven deep pore-water flow — What drives sulfide vents in oceanic mangrove peat habitats?

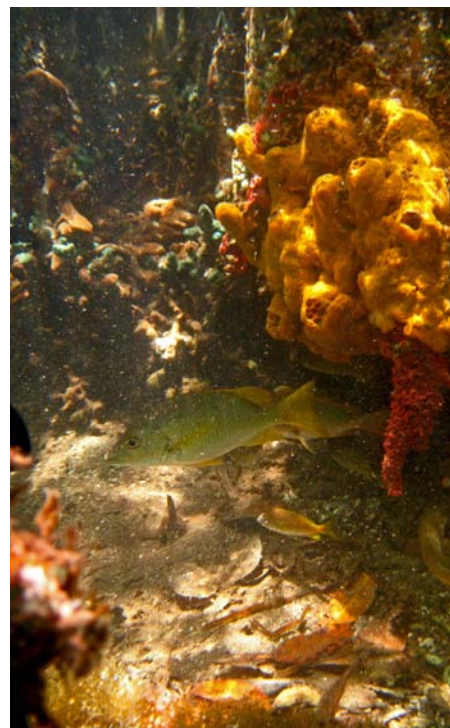
K. C. Vopel & H. Røy

Symbioses involving sulfur-oxidizing bacteria and invertebrate hosts require a source of reduced sulfur, a source of  $O_2$ , and transport mechanisms that ensure them a supply of both. In previous years, we investigated these mechanisms using the ectosymbiosis between the sessile peritrich ciliate *Zoothamnium niveum* and sulfide oxidizing Gamma-proteobacteria. This ectosymbiosis grows at the surface of overhanging vertical walls of red mangrove peat in the Tobacco Reef section of the Belize barrier reef. The filter-feeding *Z. niveum* forms contractile, feather-shaped colonies that are visible to the naked eye. The side-branches of the “feather” carry several hundred microzooids (zooid = single ciliate) in a regular pattern, as well as occasional macrozooids. The colonies grow in groups around the



openings of centimeter-scale conduits. The conduits form when mangrove rootlets decompose.

Ott et al. (1998) proposed that *Z. niveum* colonies supply their bacterial ectosymbionts with sulfide through periodic contraction into the anoxic and sulphidic diffusive peat boundary layer. Subsequent studies of the physical and chemical microenvironment around the colonies could not confirm this mechanism. Instead, it was proposed that the feature that makes the surfaces of *Z. niveum* colonies a lucrative habitat for sulfide oxidizing bacteria is the feeding current of their zooids and a mechanism that transports sulfide from its source to the surrounding of the colonies. We suggested that, rather than being a special case, exploiting sharp crossing gradients of sulfide and  $O_2$ , *Z. niveum* is more likely functionally equivalent to metazoans carrying symbionts in filtering organs such as the clams and tube worms of hydrothermal fields. Underwater measurements conducted in 2004 revealed evidence for a mechanism that transports sulfide from its source to the surrounding of *Z. niveum*. We found that the centimeter-scale peat conduits were charged with  $H_2S$  by diffusion from the decaying rootlets during periods of low boundary-layer flow speed. During these times, the feeding current of the zooids transported oxygenated seawater from outside the peat wall toward the ectosymbiotic bacteria. During periods of high flow speed,  $H_2S$ -rich seawater from the conduits was drawn along the colonies and over the bacteria. We concluded that this symbiosis exploits a combination of three transport mechanisms: (1) molecular diffusion of  $H_2S$  from the decaying tissue into



the conduits sweat-er-filled space, (2) venting of  $H_2S$ -rich seawater due to wave-induced pulsed boundary-layer current over ciliate groups and (3) the continuous and rapid feeding current generated by the host's cilia.

In July 2009, we returned to the Belize barrier reef to explore the possibility of an alternative mechanism explaining the

venting of  $\text{H}_2\text{S}$ -rich seawater from mangrove peat. Instead of relying on small scale pressure gradients generated by wave-induced pulsed flow over the groups of ciliate colonies, venting of  $\text{H}_2\text{S}$ -rich seawater may result from large-scale, tidal-driven deep pore-water flow through the peat foundation of the mangrove islands. Such flow is possible due to the pressure head caused by elevation of the peat pore water relative to the sea surface at low tide. This pressure head may drive pore-water flow through the peat foundation from the center of the mangrove island to the low-water line where it seeps out. Flooding eliminates the pressure head and stops the flow, but does not reverse the pressure gradient. Thus, the pore-water flow would be a one-way flow from the top of the peat foundation to the waterline with one displacement pulse each low tide. This process would be similar to the percolation of beaches caused by wave swash, tidal pumping and deep pore-water flow in intertidal sand flats.

Four different types of measurements were required to test the above hypothesis: 1) A time series measurement of the height of water level in the tidal channel of Twin Cays covering at least two tidal cycles; 2) A time series of oxygen or sulfide concentration in the seawater surrounding the ciliate colonies measured over the same tidal cycles; 3) An elevation profile across the peat bank normal to the tidal channel of Twin Cays at the location of the above measurements; 4) Measurement of peat permeability.

We completed the above 4 measurements in July 2009. The temperature, conductivity and depth (hydrostatic pressure) of the seawater in the tidal channel of Twin Cays were recorded by a miniature CTD from the 2nd of July until the 13th of July. The CTD was deployed at a fixed position at the peat wall of Batfish Point in about 1.5 m water depth.

Time series of oxygen and sulfide concentrations in the seawater surrounding the ciliate colonies were measured with microelectrodes mounted on a microman-

ipulator. We started the first time-series measurement on the 2nd of July using two microelectrodes, one for oxygen and one for hydrogen sulfide. For subsequent measurements, we deployed only one oxygen microelectrode per time series and recorded the sensor signals at intervals of 5 seconds (3 measurements) or 60 seconds (one measurement) starting on the 5th, 7th 9th and 11th of July. For each time series measurement, the microelectrode was placed in the centre of a group of *Z. niveum* colonies about 2 mm away from the peat surface.

To record the signals of the oxygen and hydrogen sulfide microelectrodes over periods of up to 48 hours, we deployed a new model of the Unisense Underwater picoammeter that contained suitable data loggers and powerful batteries. The instrument performed satisfactory.

In addition to the above underwater time-series measurements, we measured one elevation profile across the peat foundation at Batfish Point, Twin Cays, with a 100-m long transparent polyvinyl chloride (PVC) hose (5 mm inner diameter) filled with red water. To do so, we aligned one end of the PVC tube with a 2.5-m long pole marked with cm-scale. One person (D. T.) placed this pole at a fixed point of reference 60 m away from the peat wall of the tidal channel. The second person

(K. V.) then moved in steps of 1 m along a transect normal to the peat wall and carefully aligned the meniscus at a fixed height above the sediment at each step. Following each alignment, the person holding the reference pole at the fixed position recorded the height of the meniscus. All values were referenced to a fixed position that marked the low-water line at the peat wall.

The above measurements would not have been possible without the help from our CBC field station manager Joel, who supported every step in the construction of our low-tech measuring device, and the help from our local cook Martha, who coloured the water filled into





the transparent PVC hose using a local beetroot recipe.

The measurements of peat permeability were conducted in the Carrie Bow Cay laboratory. To do so, we collected one peat samples from each of 6 sites distributed evenly along the transect used to measure the elevation of the peat bank.

Analyses of our data will commence in November 2009. Hans Roy will model the flow of pore water through the peat bank at Batfish Point using the peat bank elevation profile, the peat permeability data and the CTD data. Kay Vopel and David Thistle will analyze the time series of oxygen and hydrogen sulfide concentrations and test for cross correlations between these time series and those of the water level in the tidal channel of Twin Cays.

## Oceanic mangrove islands: Sentinels of sea-level change

*K. L. McKee & I. C. Feller*

Rates of sediment accretion and surface elevation change have been measured at Twin Cays Belize for the past eight years, providing insight into how mangrove islands in the Caribbean Region adjust to changing sea level. 27 Surface Elevation Tables (SETs) were established in February 2001 by driving benchmarks to the Pleistocene limestone base 9-12

m beneath the islands. Changes in elevation have been measured annually through September 2009. Measurements of elevation dynamics are showing that more productive, fringing mangroves (growing along the periphery of islands and along tidal creeks) are gaining elevation, whereas the interior of the islands is sinking. Adding nutrients to some experimental sites has altered the direction and rate of elevation change. Addition of phosphorus to interior mangroves, for example, caused peat expansion and created hummocks that are now higher than surrounding areas. These findings are showing that vertical building of mangrove islands varies with health and productivity of mangroves. Even though nutrient addition had a positive effect in some

instances, there were negative effects in other areas. Thus, alteration of the nutrient regime could have unexpected and unwanted consequences for these mangrove ecosystems by disrupting the balance among processes controlling peat formation and soil elevations. Mangrove islands in the Pelican Cays that had been clear-cut and buried with dredge material were instrumented with SETs to determine if this type of disturbance accelerates relative sea-level rise and submergence of mangrove islands. Peat cores were also collected from Twin Cays and Pelican Cays to reconstruct past rates of peat accretion and vegetation history over the Holocene.



## Other Projects

### CARICOMP Monitoring

*K. Koltes & T. Opishinski*

Monitoring of physical and biological variables under the CARICOMP program continued at Carrie Bow Cay (CBC) in 2009. The CARICOMP Program is a long-term, Caribbean-wide initiative to determine the



dominant influences on coastal productivity, to monitor for ecosystem change and, ultimately, to discriminate human disturbance from long-term natural variation in coastal systems over the range of their distribution. Continuously monitored physical variables at CBC include air and water temperature, water transparency, salinity, and rainfall. Ecological variables include sea-grass productivity (biomass and growth) and coral reef community structure based on repeated sampling of 10 permanent transects established in 1993 at 10-13 m depth on the forereef. In 2009, Karen Koltes and Tom Opishinski began an analysis of the relationships among the various physical variables from the CARICOMP program and those collected by the Environmental Monitoring System. Emphasis was placed on examining the conditions that influence water quality. Among the variables examined, wind direction was found to be a good indicator of water quality around CBC. Analysis of the 15-year record of CARICOMP water quality data

also showed a significant decline in water quality along this portion of the Mesoamerican Barrier Reef, with a rate of loss of about 0.5m/yr vertical distance. Results were presented at the 34th Scientific Conference of the Association of Marine Laboratories of the Caribbean in May 2009 and will be published in the Proceedings of the Smithsonian Marine Science Symposium [Koltes, K.H. and T.B. Opishinski. in press. Patterns of Water Quality and Movement in the Vicinity of Carrie Bow Cay, Belize. *Smith. Contr. Mar. Sci.*, 38: 379-390.

### Mobile agents used by divers for undersea surveys and sampling to develop operational procedures for lunar missions

*B. Garry, L. Penland, R. Berthold, J. Dowding, & R. van Hoof*

The NASA Ames Mobile Agents team collaborated with Smithsonian Institution scientists in a series of underwater EVAs at the Smithsonian Institution's Carrie Bow Cay Field Station in Belize November 5-19, 2008. Using an ultrasonic communication system, divers communicated with each other, with support personnel topside (in a boat), and with a computer system. Building on related experiments in Hawaii and New Mexico this past summer, the expedition showed that Mobile Agents is a useful "e-science" tool for explorers to document observations, while guiding them in their work.

Two experiments were performed: 1) A standardized undersea reef survey called a "transect" and 2) a replication of Apollo 12's EVA #2. Both experiments involved formalizing the underwater operations in protocols that specified roles, tasks, locations, and schedule. The EVA protocol was represented as a Mobile Agents activity plan, by which the computer system could guide the undersea work and automatically record the association of data, tasks, and locations. The plan was rehearsed on land and then again underwater to establish smooth operations.

In the configuration found to be most practical, given the distortion of undersea speech, divers' voice commands were repeated by a topside support operator to the Mobile Agents system (in a single-user configuration called iMAS). The software agents provided information and feedback directly to the divers through the communications system. Each diver wore a full-face diving mask with speakers and microphone



connected to an Aquacom transducer. A surface station broadcast their communications, which were recorded. A third transducer topside connected to the iMAS computer so the software agents could speak to the divers on the voice loop. Undersea operations were recorded in high-definition video, thus capturing the full interactions among divers and computer agents. To enable marking locations of samples, photographs, and voice notes, a buoy with a GPS transmitter was towed by a diver, and this data was registered by the iMAS system.

The reef transect experiment included placing a grid and taking photographs over 5 meters and was completed in a one-hour dive. For the Apollo 12 EVA #2 experiment, divers wore extra weight to simulate lunar gravity (1/6 g), and they walked on a sandy bottom. The experiment replicated the layout of workstations and number of observations (photographs, samples) in the historical EVA, and by virtue of the limited air supply and decompression constraints provided a partial analog to lunar EVA logistics.

This protocol enables comparing work efficiency and operations concepts across diverse lunar, volcanic, and undersea environments. Eight dives were required to replicate the original 4 hour Apollo 12 EVA #2, involving walking 1.45 km and taking 259 photographs and sampling at 17 workstations. Preliminary analysis suggests that future work should focus on tools for creating plans and specifying voice command options in the field, plus consolidating, sharing, and analyzing data after EVAs.

Background:

NASA's Moon and Mars Analogue Mission Activities (MMAMA) program aims to develop operation concepts for surface science scenarios relevant to the preparation of planned human missions to the Moon and Mars. The current project "Computer-Assisted Surface Science Scenarios to Develop Operational Procedures for Manned Lunar and Martian Missions Using the Individual Mobile Agents System" (PI: Brent Garry, Smithsonian) collects science data related to geologic research on lunar and Martian lava analog flows and establishes training scenarios using technology to assist Astronauts on an EVA.

Using the method of empirical requirements analysis, this investigation has three overarching questions: How can geology be documented efficiently and effectively using computer technology? What science-based field exercises can be developed to train Constellation Astronauts? How do simulated EVAs at three analog field sites compare to actual Lunar EVAs?

The iMAS system tracks the scientist's progress through an EVA, makes predictions about ability





to complete an EVA on schedule, provides spoken alerts when parameters exceed nominal thresholds, answers spoken queries about status, and records data for off-line analysis. iMAS is designed to increase astronaut self-sufficiency during an EVA, while improving safety and efficiency through context-sensitive monitoring, advising, and logging.

The Mobile Agents team has been developing agent-based



systems for surface exploration since 2000 and has been testing these systems in authentic field conditions involving a variety of instruments and robots. iMAS is currently used in POGO experiments at JSC. The full networked version of Mobile Agents is used in spaceflight operations at JSC for automating routine aspects of file transfers between the International Space Station and ground support.

## Underwater photography

*C. Clark & D. Hurlbert*

We are new to digital underwater photography and aimed at testing new housings for proper placement of the port, which is critically important to the quality of the resulting image. The advantages of instant access to the digital image also allowed us to perfect our underwater strobe lighting techniques for both wide angle and macro photography. Several thousand underwater photographs, including wide-angle and extreme close-up are currently sorted and evaluated.





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