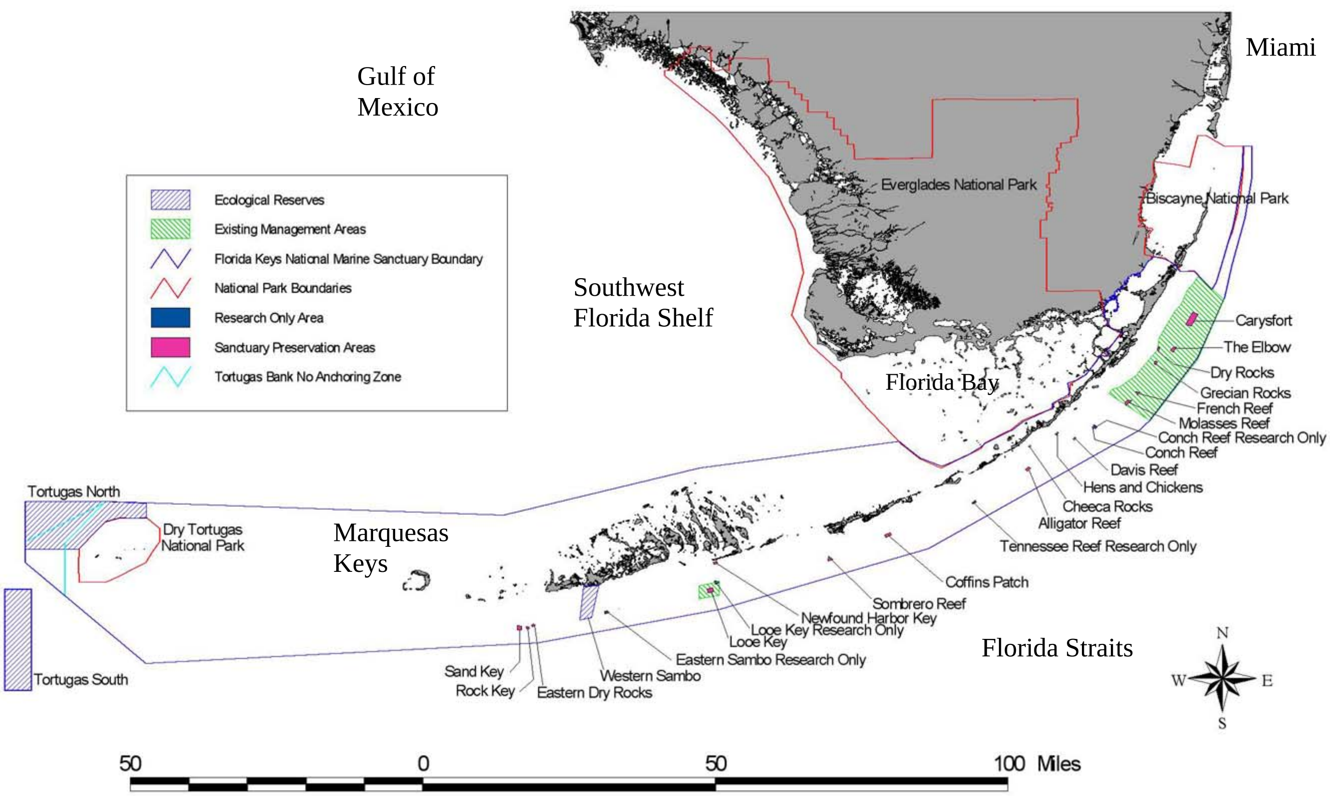
National Oceanic and Atmospheric Administration
Florida Keys National Marine Sanctuary

U.S. Environmental Protection Agency

State of Florida

2002-03 Sanctuary Science Report: An Ecosystem Report Card After Five Years of Marine Zoning



http://floridakeys.noaa.gov/research_monitoring/welcome.html
Final: 2 October 2006

FLORIDA KEYS NATIONAL MARINE SANCTUARY

Preface

In this *2002-03 Sanctuary Science Report* we include updates on the three long-term, status-and-trends monitoring projects of the Water Quality Protection Program (WQPP) and on the projects that comprise the Marine Zone Monitoring Program. These two monitoring programs are inextricably related; population and community changes that result from the Sanctuary's network of fully protected marine zones occur in the context of large-scale environmental characteristics measured by the water quality, seagrass, and coral reef evaluation and monitoring projects of the WQPP. This year we have added a set of summary reports on socioeconomic research projects, and continue to present findings of partnership projects with NOAA National Centers for Coastal Ocean Science. After presenting reports on two long-spined urchin (*Diadema antillarum*) restoration projects, we conclude with lists of permitted research projects for the years 2002 and 2003.

We thank the large group of investigators working in the Florida Keys National Marine Sanctuary for designing projects and collecting the ecological and socioeconomic data we need to evaluate the condition of the Sanctuary's resources and how the ecosystem as well as human uses and perceptions respond to management actions.

Brian D. Keller
Science Coordinator

Scott Donahue
Associate Science Coordinator

Suggested citation:

Keller, B.D. and S. Donahue. ed. 2006. 2002-03 sanctuary science report: an ecosystem report card after five years of marine zoning. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries, Florida Keys National Marine Sanctuary, Marathon, FL.

Contents

Diadema Restoration Projects

Permitted Research Projects

Executive Summary

Circulation and Exchange of Florida Bay and South Florida Coastal Waters

The coastal ecosystem of South Florida is comprised of distinct marine environments. Circulation of surface waters and exchange processes, which respond to both local and regional forcings, interconnect different coastal environments. In addition, re-circulating current systems within the South Florida coastal ecosystem such as the Tortugas Gyre contribute to retention of locally spawned larvae.

Variability in salinity, chlorophyll, and light transmittance occurs on a wide range of temporal and spatial scales, in response to both natural forcing, such as seasonal precipitation and evaporation and interannual "El Niño" climate signals, and anthropogenic forcing, such as water management practices in south Florida. The full time series of surface property maps are posted at *www.aoml.noaa.gov/sfp*.

Regional surface circulation patterns, shown by satellite-tracked surface drifters, respond to large-scale forcing such as wind variability and sea level slopes. Recent patterns include slow flow from near the mouth of the Shark River to the Lower Keys, rapid flow from the Tortugas to the shelf of the Carolinas, and flow from the Tortugas around the Tortugas Gyre and out of the Florida Straits.

The Southwest Florida Shelf and the Atlantic side of the Florida Keys coastal zone are directly connected by passages between the islands of the Middle and Lower Keys. Movement of water between these regions depends on a combination of local wind-forced currents and gravity-driven transports through the passages, produced by cross-Key sea level differences on time scales of several days to weeks, which arise because of differences in physical characteristics (shape, orientation, and depth) of the shelf on either side of the Keys. A southeastward mean flow transports water from western Florida Bay, which undergoes large variations in water quality, to the reef tract.

Adequate sampling of oceanographic events requires both the capability of near real-time recognition of these events, and the flexibility to rapidly stage targeted field sampling. Capacity to respond to events is increasing, as demonstrated by investigations of the 2002 "blackwater" event and a 2003 entrainment of Mississippi River water to the Tortugas.

Water Quality, Seagrass, Coral Reef, and Episodic Event Monitoring

Results from the Water Quality Monitoring Project, an element of the Water Quality Protection Program (WQPP; http://ocean.floridamarine.org/fknms_wqpp/), indicate that overall nutrient concentrations were greatest in waters on the Gulf of Mexico side of the Keys and lowest on the Atlantic side along the reef tract and in the Tortugas region. Inshore waters differed from reef tract waters mainly by having higher concentrations of nitrate. Inshore waters of the less-inhabited Upper Keys exhibited lower nitrate concentrations than the Middle and Lower Keys. Interestingly, inshore waters in the Tortugas area were similar to those of reef tract sites off the less-inhabited Upper Keys. Essentially, there was no elevation of nitrate in the inshore waters of the Tortugas, supporting the suggestion that the source of nitrate in the Keys is shoreline development.

Waters on the Gulf side of the Keys exhibited the highest total phosphorus concentrations and turbidity. Waters on the north side of the "Backcountry," extending west over the northern Marquesas Keys, exhibited the highest chlorophyll *a* concentrations. This area is most heavily influenced by advection of Southwest Florida Shelf waters.

Trends may be perceived as local when they occur regionally but at more-damped amplitudes. This spatial autocorrelation in water quality is a property of highly interconnected systems such as coastal ecosystems driven by similar hydrological and climatological forcings. There have been large changes in water quality over time, but no sustained monotonic trends have been observed. It is important to keep in mind that trend analysis is limited to the window of observation; trends may change with additional data collection. Rather than thinking of water quality monitoring as a static, non-scientific pursuit it should be viewed as a tool for answering management questions and developing new scientific hypotheses. Data from the FKNMS are integrated with other parts of a South Florida water quality monitoring network (http://serc.fiu.edu/wqmnetwork/).

Florida Bay Watch was a volunteer-driven program managed by The Nature Conservancy (TNC) in which volunteers were trained in basic methods of sampling water quality for one or more Florida Bay Watch projects (Nearshore Fixed Stations, Content Keys, and Key West Salt Ponds during this phase of the program). The Nearshore Fixed Stations project occurred at various locations along the Keys between 1994 and 2002; there were 8,510 sampling events for which five parameters were analyzed: temperature, salinity, total nitrogen (TN), total phosphorus (TP), and chlorophyll *a* (Chl. A). All five parameters were significantly greater during the wet season than during the dry season. Salinity was significantly greater for oceanside stations, while samples collected from the bayside were significantly greater for TN, TP, and Chl. A. There was no significant difference between oceanside and bayside temperatures. Temperature, TN, and Chl. A levels were significantly higher along developed shorelines (canals/boat basins) compared to natural shorelines. Temperature values were similar for all three regions of the Keys, as were salinity and TP. The Upper Keys had the highest TN and Chl. A levels.

Sampling at the Content Keys occurred from 1997 until 2000 near the surface and bottom (approximately 6 m depth). Salinity was significantly higher for samples collected near the surface, while TN, TP and Chl. A levels were significantly higher for samples collected at depth. Sampling at the Salt Ponds occurred from 2001 until 2002. Average temperature, salinity, and TN were all higher in the Salt Ponds than at Lower Keys nearshore fixed stations as expected because of the shallow depth of the Salt Ponds. The source of elevated TN may have been from stormwater, wastewater, or natural inputs such as bird droppings.

Florida Keys Watch was a canal water quality monitoring program, managed by TNC, designed to assess levels of bacterial and human-borne viral contamination in 17 canals throughout the Florida Keys. Every two weeks, a team of two volunteers and TNC staff collected environmental data and water samples from all 17 stations. Sampling also occurred following episodic events, such as a heavy rainfall. No stations exceeded the EPA recommended enterococcus maximum (104 CFU/100 ml) for samples collected following "no rainfall," while 59% of these stations exceeded the limit following a rainfall. Analysis of samples collected after there had been no rain event revealed that 12 stations were deemed acceptable by Florida Healthy Beaches standards, five stations were moderate, and no station was poor. Samples collected after heavy rain events revealed that only three stations were deemed acceptable, four stations were moderate, and 10 stations were poor. The average dissolved oxygen level in the series of canals was determined to be 3.52 mg/l, which fell below the acceptable limit of 4.0 mg/l.

Seagrass monitoring, another component of the WQPP, is designed to determine the distribution and quantitative status of seagrasses within the Sanctuary, quantify seagrass primary production, define baseline conditions for seagrass communities, determine relationships between water quality and seagrass status, and detect trends in the distribution and status of seagrass communities. The spatial pattern of seagrass variation and agreement of these changes with model predictions of nutrient-induced modifications of the system suggest a regional-scale change in nutrient availability. Nevertheless, it appears that there have not been large-scale trends in abundance of dominant plants over the past seven years, even though increases in macroalgal abundance have occurred at several sites, consistent with an increase in nutrient availability. There have been long-term shifts in the N:P ratio in seagrass leaves, which also indicate increases in nutrient availability. It is noteworthy that these sites were relatively close to shore in the Middle and Lower Keys.

The seagrass bed that carpets 80% of the Sanctuary is part of the largest documented contiguous seagrass bed on earth, and it is vital for the ecological health of the marine ecosystem of South Florida (http://www.fiu.edu/~seagrass/). Seagrasses were completely lost at 3 of 30 permanent sites during recent hurricanes; benthic communities were relatively stable at the remaining 27 sites. The response of seagrasses to eutrophication may be on the order of decades, so long-term monitoring and further research clearly are continuing needs.

The Coral Reef Evaluation and Monitoring Project (CREMP), the third monitoring project of the WQPP (http://www.floridamarine.org/features/category_sub.asp?id=2360), documented a decline in species richness for all habitat types from 1996 to 2002. Overall, the number of stations containing diseased coral, the number of coral species with disease, and the different types of observed diseases all increased. Black band disease peaked in 1998, while “white” and “other diseases” generally have increased over the past six years, other than a dip in the number of affected stations in 2000. Between 1996 and 2002, a 38% decline in stony coral cover was observed Sanctuary-wide. However, changes between 1999 and 2002 were not statistically significant. The significant declines in coral cover observed from 1997 to 1998 (11.4% to 9.6%) and from 1998 to 1999 (9.6% to 7.4%) were concurrent with a severe mass bleaching event and strong storms including Hurricane Georges in 1998. Sanctuary-wide, in 2002, the benthic community at CREMP sites was composed of 66.8% substrate, 11.0% octocoral, 9.3% macroalgae, 7.5% stony coral, 2.5% sponge, 2.2% zoanthids, and 0.6% seagrass. The six coral species with the greatest mean percent cover Sanctuary-wide in 1996 were *Montastraea annularis*, *M. cavernosa*, *Acropora palmata*, *Siderastrea siderea*, *Millepora complanata*, and *Porites astreoides*. *Acropora palmata* (elkhorn coral) is well recognized as a primary framework species. Striking changes were documented for this species as well as *A. cervicornis* (staghorn coral) and *Millepora complanata*, a once-dominant species of fire coral. The mean percent cover of *A. palmata* decreased 91% from 1.1% in 1996 to 0.1% in 2002. Between 1996 and 2002 percent cover of *A. cervicornis* decreased 94%, from 0.20% to a barely detectable 0.01%. Also, between 1996 and 2002 percent cover of *M. complanata* declined from 1% to 0.03%.

The decline in coral cover observed on Florida reefs is similar to declines reported for reefs elsewhere in the Caribbean and Gulf of Mexico. It is important to note that declines in coral cover and numbers of species are not necessarily a recent phenomenon and are likely the result of multiple, chronic, and acute stressors acting at local, regional, and global scales over long periods. The comprehensive monitoring data set on stony coral cover, species richness, bleaching, disease, bioeroders, temperature, fate tracking, human enteroviruses, and abundance will assist in development of landscape-seascape program models to characterize physical, chemical, and biological stressors. These data will also assist managers in determining potential downstream effects of Everglades restoration.

The Marine Ecosystem Event Response and Assessment (MEERA) Project continued to log hundreds of observations reported by researchers, State and Federal personnel, and residents, as well as fishers and divers (http://www.mote.org/research/trl/MEERA.phtml). These mainly included reports of algal blooms and discolored water, sea turtle strandings, coral disease and bleaching, and fish disease or fish kills as well as various mortality events, invasive species, and a range of unusual observations. Response efforts included the collection, analysis, and shipping of samples; photo-documentation of reports or events; and providing assistance or logistical support for other researchers and organizations.

Marine Zone Monitoring Program

Coral reef community structure and coral population dynamics have been monitored and compared between three Fully Protected Marine Zones (FPMZs) and adjacent reference sites since 1998; a fourth pair of sites was added to the study in 2002. Coral cover remained consistently different between sites from 1998 to 2002. As in previous years, the Western Sambo Ecological Reserve (ER) shallow site exhibited considerably higher cover than the other shallow sites. The cover of encrusting octocorals increased at all shallow and deep sites from 2000 to 2001, and this trend continued at most sites from 2001 to 2002. The cover of sponges also increased from 2001 to 2002 at all shallow sites.

There appear to be very few indications that FPMZs have higher coral recruitment than adjacent reference sites. Shallow sites in both the Lower and Upper Keys have had nearly uniform recruitment rates of three to five new colonies/m^2/yr, with the exception of the Western Sambo ER shallow site, which has had recruitment of about 10 colonies/m^2/yr since 2000. The overall impression is that recruitment is highly site-specific, with an indication of higher recruitment at Lower Keys deep sites. Differences in patterns of larval settlement in the Upper and Lower Keys may indicate differences in larval supply to these regions.

Juvenile coral mortality rates are generally more consistent (20 to 40% per year) across sites and depths with little distinction between FPMZs and reference sites since 1999; no distinctions appear between the Lower and Upper Keys sites. This might indicate that factors that contribute to juvenile coral mortality are more uniformly distributed along the Florida Reef Tract than the factors that promote recruitment. However we lack any data with regard to these potential agents of coral mortality.

Very few of the massive framework-building species have recruited successfully, if at all. The fact that other broadcasting species are more successful indicates that water column processes are not limiting factors. Patterns of mortality in the marked juvenile corals did not show strong differences between species, within years, or across depths. Also, there do not appear to be differences in mortality rates between FPMZs and reference sites.

Efforts by the NOAA National Undersea Research Center/University of North Carolina at Wilmington (NURC/UNCW) Rapid Ecological Assessment program consisted of a summer 2002 benthic coral reef sampling in the Florida Keys, which was partnered with a Keys-wide cruise of reef fishes and spiny lobster, focusing on hard-bottom and coral reef habitats from Biscayne National Park to the Tortugas region. The primary focus of the 2002 fieldwork was to obtain information on community structure and condition of reef benthos at 15-21 m depth (fore reef) along the Florida Reef Tract to compare to similar studies carried out in 1995. The fieldwork also served to supplement existing data sets on the status of reef and hard-bottom communities in Biscayne National Park, the Florida Keys, and Tortugas region. The 2002 sampling represents the fifth consecutive year of large-scale surveys of hard-bottom and coral reef habitats conducted by NURC/UNCW.

In addition to the deeper fore reef sites, the 2002 work also included patch reef, hard-bottom, and reef terrace communities offshore of Biscayne Bay, the Florida Keys, and in the Dry Tortugas. The 2002 field effort complemented Keys-wide benthic surveys of 80 sites during 1999, 45 sites across the continental shelf in the lower Florida Keys region during 2000, 86 sites Keys-wide during 2001, and 60 sites sampled in the Tortugas region during 1999-2000. During 2002, 64 sites were sampled from Biscayne National Park to the Tortugas. The deeper reef focus in 2002 was designed specifically to compare with results obtained in 1995 during a previous Keys-wide expedition. During 2002, three of the Sanctuary's 24 FPMZs were visited, with 10 additional sites surveyed just seaward of the zone boundaries in deeper water and habitats similar to sites surveyed during 1995. Benthic surveys by the NURC/UNCW project team were complemented by reef fish surveys conducted by personnel from the Rosenstiel School of Marine and Atmospheric Science (RSMAS) of the University of Miami and NOAA National Marine Fisheries Service (NMFS).

Variables measured during 2002 were similar to those sampled in previous years, namely coverage, species richness, gorgonian density, coral density and size, and coral condition. Several variables were included at some sites that were sampled during the 2001 assessment: urchin density and size; density of anemones, corallimorpharians, opisthobranch mollusks, cleaner shrimps, spiny lobster, and arrow crabs, as well as in situ measurements of topographic complexity. Several hundred underwater digital photographs were taken to further develop an archive of Florida Keys reef and hard-bottom habitats and tools for taxonomic identification of benthic invertebrates.

Key findings of the NURC/UNCW Rapid Ecological Assessment program include:

- Similar to earlier expeditions, offshore patch reefs exhibited some of the highest coral cover in the Biscayne and Florida Keys regions, ranging from 4% to nearly 28%.
- High-relief spur and groove and reef terrace habitats exhibited the highest coral cover in the Tortugas region and reef terraces exhibited the highest coral cover among all sites surveyed in 2002, ranging from 12% to 51%.

- Surprisingly, coral cover did not tend to be greater within FPMZs, contrasting with 2001 surveys of high-relief spur and groove reefs, when sites within FPMZs tended to have greater coral cover than adjacent reference sites.
- Among the four regions surveyed in low-relief spur and groove habitat, coral cover was greatest in the Dry Tortugas (20.3%), followed by the Middle Keys (7.4%), the Lower Keys (6.8%), and the Upper Keys (3%), the latter including sites east of Biscayne Bay.
- The pattern on deeper spur and groove reefs was opposite to that observed for shallower spur and groove reefs during 2001, when reefs in the Upper and Lower Keys yielded the greatest coral cover.
- A total of 46 coral, 33 gorgonian, and 80 sponge species were found.
- From Biscayne to the Lower Keys, gorgonian densities were generally similar among habitats, regions, and management protection. Scleractinian coral densities were more variable and displayed some patterns among habitats and regions.
- Similar to results from 1999-2001, all of the sampling locations yielded very low densities of urchins, particularly the long-spined sea urchin *Diadema antillarum*. Some locations had relatively high densities of other species, particularly the reef urchin *Echinometra viridis*.

Since no-take protection was initiated in 1997, significant density increases were observed by the NMFS/RSMAS team for several exploited reef fish species in FPMZs compared to fished reference areas. Among exploited species, mean densities were higher in FPMZs for Gray Snapper, Black Grouper, and Yellowtail Snapper. Concordance between FPMZs and reference areas was observed for changes in density for Stoplight Parrotfish and Striped Parrotfish, two species not directly exploited. The passage of Hurricane Georges (a strong hurricane) and Mitch (a weak hurricane) in the fall of 1998 resulted in declines of mean density at both fished and unfished sites in 1999 for the two non-exploited parrotfishes and Gray Snapper. No detrimental impacts on fish densities were noted following the passage of Hurricane Irene, a weak hurricane that passed over the Lower Keys in the fall of 1999.

Roving diver surveys by the Reef Environmental Education Foundation (REEF) Advanced Assessment Team show that black grouper has exhibited a significant increase throughout the Florida Keys between 1994 and 2002. In general, since sites were protected in 1997, black grouper have been seen with higher frequency in FPMZs than in reference areas. These findings are consistent with those of the NMFS/RSMAS team, summarized above. Nassau grouper, a protected species in Florida, has shown slight increases over time and in 2002 reached an all time high, since REEF data collection began, of 22% sighting frequency at FPMZs. Red grouper, a relatively rare species, had increased at many sites in 1999 and 2000, but sighting frequency has decreased over the last two years. The average abundances of four carnivore species (gray snapper, yellowtail snapper, schoolmaster, and hogfish) showed little difference between fully protected and reference sites. A dramatic decline in rock beauty has been seen, while other angelfish populations have remained relatively stable. This decline was associated with decreasing collections for the aquarium trade in recent years.

In 1997, investigators with the Florida Fish and Wildlife Conservation Commission/Fish and Wildlife Research Institute (FWRI) found little difference between the number of spiny lobsters (*Panulirus argus*) inside FPMZs and reference areas, but after five years of protection there were almost twice as many lobsters inside three Lower Keys FPMZs as outside. There usually were more lobsters in FPMZs than in reference areas during the closed fishing season, and the number of lobsters observed in reference areas always decreased dramatically during the fishing season. Since 1999, abundance of legal-sized lobsters has always been greater in two of the three FPMZs than in reference areas; however, legal-sized lobster abundance was not higher in the Looe Key Sanctuary Preservation Area (SPA) than in its reference area despite the fact that Looe Key has been a lobster reserve since 1981. This may reflect the small size of the SPA compared to the home range of lobsters denning inside it. In general, mean lobster size was below the legal limit in FPMZs and reference areas in 1997. Since implementation of marine zoning in 1997, mean lobster size in FPMZs has been larger than legal size and comparatively larger than in reference areas. Mean size of male lobsters on offshore patch reefs in the Western Sambo Ecological Reserve has increased 10 mm in five years. Abundance of very large lobsters (≥100 mm carapace length) increased in the Western Sambo reserve relative to its reference area with males becoming larger as well as more abundant, suggesting that some lobsters remain in the ecological reserve for an extended period.

Queen conch (*Strombus gigas*) have been protected by State law from collection for approximately 20 years. Monitoring by FWRI staff shows that conch are distributed in well-defined aggregations that are not entirely encompassed by FPMZs, with the majority of adult conch in the Lower Keys (estimated abundance of 23,640, about 77% of the total). Over 5,000 and over 1,500 adults occurred in the Upper and Middle Keys, respectively. By contrast, juvenile conch were more evenly distributed, with the majority in the Upper Keys (estimated abundance 15,337, about 45%) and Lower Keys (12,322, 36%); about 6,400 juveniles were found in the Middle Keys. Since 1997, the total adult conch population has grown by about 46%, while juvenile abundance has increased by about 240%. From 2000 to 2001, a large amount of recruitment of juvenile conch occurred throughout the Keys. The results of the sixth year of queen conch monitoring support those of earlier years: conch are recovering, albeit slowly.

Socioeconomic Research and Monitoring Program

The goals of the project, “Importance and Satisfaction Ratings, A Five-Year Comparison (1995-96 to 2000-01,” are to monitor and assess knowledge, attitudes, and perceptions of Sanctuary management strategies and regulations. This project monitors and assesses perceptions of the conditions of 25 natural resource attributes, facilities, and services by both residents of Monroe County and visitors to Monroe County and the FKNMS. Results show that many key natural resource attributes, facilities, and services have increased in importance to people, while satisfaction with these natural resource attributes, facilities, and services has declined. Plugging these results into a conceptual model linking the economy and environment leads to potentially dire predictions of the future natural resource-based economy if actions are not taken to reverse these trends.

Another possible consequence of negative trends in satisfaction is the cost of attracting and educating “new” visitors. The results of this project show that for many natural resource attributes, facilities, and services, satisfaction ratings are not only in decline, they are also relatively lower for more-experienced visitors. The loss of repeat visitors raises the marketing costs of attracting “new” visitors and raises the costs of educating “new” visitors on how to interact with the areas’ natural resources and support sustainable tourism.

A second project, "Linking Ecological and Socioeconomic Monitoring Results, 1995-96 to 2000-01," had the goal of testing whether user perceptions of resource conditions are in agreement with what marine scientists are observing in actual conditions. There were both agreements and disagreements between user perceptions and scientific findings. Areas of disagreement may indicate needs for further efforts in education and outreach. In some cases, residents and visitors differed in their perceptions relative to scientific findings. When users perceive and scientists measure declines in natural resources, there is economic justification to make investments to solve these problems before they translate into economic losses.

A third project, "Sanctuary Preservation Areas and Ecological Reserves: Monroe County Reef-Using Residents' Opinions on 'No-Take' Zones," utilized a stratified-random sample of registered boaters with responses from nearly 600 boat users in Monroe County/FKNMS. An overwhelming majority of all reef users (78%) and recreational fishers (76%) supported the currently designed no-take zones. In contrast to expectations, results did not support a "Not In My Backyard" hypothesis; Monroe County residents were generally not in support of no-take zones in the three counties to the north, while supporting the creation of additional no-take zones in the FKNMS. Using a conservative measure, residents using Sanctuary Preservation Areas (SPAs) and Ecological Reserves (ERs) would support having 25% or more of coral reefs protected in no-take zones; non-users would support 20% or more. The current level of protection of coral reefs is 10% (6% protection across all habitats).

A fourth project is monitoring the spatial pattern and intensity of on-water recreational use, especially with regard to activities inside SPAs and ERs. Another major objective is to monitor and assess visitor and resident knowledge of Sanctuary management strategies and regulations, and their attitudes and perceptions regarding their appropriateness and effectiveness. This project established 2000-01 baselines of SPA and ER use, economic user value, and user perceptions of conditions of SPAs and ERs. A majority of resident reef users used SPAs and/or ERs (58%), compared to 44% of visitors; 16% of visitors did not know whether they had used a SPA or ER. There were almost 1.2-million person days of snorkeling and scuba diving in SPAs and ERs, nearly evenly split between residents and visitors. This project includes detailed analyses using socioeconomic profiles of users and comparative importance-satisfaction ratings. It appears that visitors already perceive SPAs and ERs as relatively higher quality areas in contrast to residents, who do not.

A fifth project seeks to determine the economic valuation of marine reserves based on diver attitudes and preferences, from late 2002 until early 2004. Preliminary results indicate that users value marine reserves and multiple-use dive sites as centers of marine resource management and recreation. Findings also demonstrate that respondents generally view all dive sites favorably, in terms of their ecological and social conditions, suggesting the efficacy of local area management, as it relates to this user group. Finally, most divers and snorkelers report congruence between expected conditions and personal experiences, which may explain the high trip satisfaction ratings.

The socioeconomic monitoring program of commercial fishing panels focuses on the commercial fishing industry in the Florida Keys, effects of FKNMS regulations on commercial fisheries, and additional impacts to the local economy. Information collected in the first five years suggests that harvest totals and net earnings increased or remained stable in the first three years but declined in the fourth year with some recovery in the most recently surveyed year (2001-2002). Importantly, the information collected suggests that extra-Sanctuary factors may contribute strongly to interannual fishery harvests and production. Most panel members (94%) do not believe that the fully protected marine zones have increased or replenished stocks in the region, and none of the fishers believes that his group has been the primary beneficiary of the zoning strategy. These statistics are similar to results from a 1995-96 study. As in the 1995-96 study where 78% of commercial fishers interviewed opposed Sanctuary designation, a majority of the respondents (68%) remains against the establishment of the Sanctuary. Nevertheless, fishing is quite prevalent around fully protected marine zones, and many species are fished or collected near the boundaries of these zones.

Partnership Projects with NOAA National Centers for Coastal Ocean Science
Since 1999, scientists at the Center for Coastal Environmental Health and Biomolecular Research and several collaborating organizations have been examining corals at the cellular level, using an integrated Cellular Diagnostic System (CDS). The CDS is designed to diagnose whether an organism is stressed and to identify likely stressors. The assay, which measures changes in cellular parameters, quantifies whether the structural integrity of the cell is compromised, the type of stress, and whether defenses have been mounted against a particular stress. Results using this bioassay technique enabled scientists to determine whether a coral population was being stressed by a global stressor such as high sea surface temperatures or by a local stressor such as pesticides. When used in conjunction with other technologies and monitoring methods, this biotechnology was able to identify potential stressors. Data collected on *Montastraea annularis* at four sites supported the possibility that coral cellular damage, measured in 1999, resulted from a global stressor (La Niña sea-surface temperature effects). In contrast, in 2000 patterns of these same parameters were radically different and were not correlated with sea-surface temperatures; instead, stresses on corals noted at two sites originated from local impacts. In addition, information from the CDS can be used to make a prognosis of coral health. Levels in a single biomarker allowed the prediction of whether or not a coral colony would bleach with a 96% probability a full six months prior to the observation of bleaching in the environment.

Scientists at the Center for Coastal Fisheries and Habitat Research (CCFHR) conducted a field experiment to assess the effectiveness of installing fill material encapsulated in biodegradable fabric tubes to restore propeller scars. The experiment was designed to test the efficacy of sediment tubes, alone and in conjunction with bird stakes and *Halodule wrightii* seagrass planting units and to re-grade injuries to enhance regrowth of seagrass from the margins of propeller scars. The major findings of the study were: 1) sediment tubes are a clean and efficient means of deploying fine grained sediments into excavations in seagrass beds; 2) *Halodule wrightii* can be transplanted into sediment tubes; 3) sediment tubes degrade fast enough to allow for growth of seagrass transplants; and 4) sediment tubes do not inhibit *Thalassia testudinum* growth or algal colonization. The investigators recommend that sediment tubes be tested for use in larger blowholes where lateral growth of seagrass into excavated injuries is very slow. By installing bird stakes with sediment tubes and adding *H. wrightii* transplants it may be possible to obtain sediment-stabilizing cover of the faster-growing seagrass within two years, instead of waiting several years or even decades for seagrasses to grow in from the perimeter of a large injury. This approach needs further testing.

In a companion study, scientists at the CCFHR, in partnership with the Florida Fish and Wildlife Conservation Commission used experimental manipulation to assess effects of excavation depth and filling/regrading with carbonate pea rock on seagrass recovery into simulated propeller scars. Results of this study demonstrated that injuries to seagrass banks that exceeded 10 cm in depth had significant impacts on the densities of *Thalassia testudinum* and *Syringodium filiforme*; in some treatments those impacts persisted three years after initiation. In both experiments, *T. testudinum* short-shoot density in all treatments returned to control levels between the second and third year following injury. *Syringodium filiforme* short-shoot densities, however, remained elevated in most deep (> 20 cm) treatments through the end of the experiment. Total macroalgal cover also tended to be lower in more disturbed treatments. Although *T. testudinum* short-shoot densities and treatment depths had returned to pre-injury levels in roughly two to three years, treatments continued to impact *S. filiforme* short-shoot counts and macroalgal cover. Filling of injuries with pea gravel provides protection from erosion, does not inhibit growth of *Thalassia testudinum*, and might minimize stress of competition from *Syringodium filiforme*. The placement of fill into larger blowhole injuries that take decades to recover should diminish the probability of further erosion and enhance recovery by allowing regrowth of seagrasses.

Since 2000, a second team of scientists at the CCFHR has been investigating the refuge effect of the Tortugas Ecological Reserve (TER) by focusing on: 1) an extensive habitat characterization of the benthos in and around the TER, 2) a multiple stable isotope analysis of the food web supporting fish production in the TER, 3) an examination of the abundance and composition of reef fishes in the reserve, and 4) an examination of the effects of trawl exclusion on benthic habitats located in the TER. Analysis of a habitat map is ongoing. The majority of fish analyzed so far exhibit a C isotope signature consistent with a food web based on benthic primary producers. Additional results will help determine whether there is a significant geographic or reserve effect on food webs. Nitrogen isotope values can help to predict potential ecosystem effects of changes in average fish size as the result of no-take regulations. Six fish species (representing the most abundant species in each of six important reef fish families) increased in number and size within the Reserve compared to Dry Tortugas National Park and areas fully open to fishing. Relaxation of trawling pressure has increased benthic biomass and diversity in the Tortugas North ER. It appears that these soft-bottom communities respond quickly to relaxation of the disturbance of trawling and further changes may occur over time with development of a more stable assemblage of attached invertebrates in the more physically stable parts of the shelf.

***Diadema* Restoration Projects**

A *Diadema* restoration project conducted by The Nature Conservancy utilized "corrals" made of nylon mesh deployed around coral heads and stocked with densities of adult urchins approximating pre-die-off densities; unmanipulated coral heads served as reference sites. Corrals stocked with wild urchins quickly displayed a drastic reduction of turf algae; the percentage of corals, sponges, gorgonians, and bare substrate within corrals remained relatively level throughout the duration of the project. Three months after "seeding" with coral larvae, corralled areas contained many more juvenile corals (0.5-1.5 cm) than had been initially surveyed.

A second project was conducted in two parts: translocation of small *Diadema* from unstable rubble habitat to patch reefs (Nedimyer and Moe) and surveys of benthic communities in urchin-addition treatments and unmanipulated reference sites (Center for Marine Science Research and NOAA's National Undersea Research Center, University of North Carolina at Wilmington). Gradual urchin losses over the year+ term of the project indicated that predation was the main cause of population decline and not mortality due to storms. This part of the study demonstrated that a translocation program of juvenile urchins from rubble zones to reef areas can establish and maintain relatively dense populations of *Diadema* in small reef areas. Translocation could substitute for natural recruitment and maintain a reproductively effective population. Urchin densities on the experimental patch reefs one year after the translocation averaged nearly 1 individual/m^2, similar to urchin density estimates in the Florida Keys prior to the 1983-84 mass mortality event. The coverage of stony corals and crustose coralline algae increased, while the coverage of brown foliose algae declined on experimental patch reefs. In contrast, stony coral and crustose coralline algal cover declined on control patch reefs, but increased for brown foliose algae. Juvenile coral densities increased at all sites, but density increases were markedly greater on both experimental sites, reflecting greater densities of smaller juveniles (< 1.5 cm diameter), especially *Porites astreoides* and *Siderastrea siderea*. These results are similar to previous investigations of the effects of artificially enhanced or naturally recovering urchin densities on coral reef benthos, especially as they pertain to changes in algal composition and juvenile coral densities.

Permitted Research Projects

This report includes lists of permitted research projects for 2002 (83 projects) and 2003 (57 projects), which show the range of investigators and topics of study in the Florida Keys National Marine Sanctuary.

Introduction

Florida's coral reef tract is one of the largest bank-barrier reef systems in the world. All but the northernmost reefs lie within the boundaries of the National Oceanic and Atmospheric Administration's (NOAA) Florida Keys National Marine Sanctuary (FKNMS). The 9844-km^2 Sanctuary was designated in 1990 to protect and conserve nationally significant biological and cultural marine resources of the area, including critical coral reef habitats, seagrass beds, hard-bottom communities, and mangrove shorelines.

The ecologically important marine resources of the Florida Keys are being impacted by a variety of stressors, both natural and human-caused. This is evidenced in a decrease in coral cover and species diversity at most reefs and an increase in coral diseases and bleaching in recent years. Boat groundings, propeller scarring of seagrass, accumulation of debris, and improper anchoring practices have been responsible for thousands of hectares of resource damage. Serial overfishing has dramatically altered reef fish and other exploited populations, contributing to an imbalance in ecological interactions that are critical to ecosystem structure and function. Eutrophication and inadequate wastewater and stormwater treatment have degraded nearshore waters. Altered freshwater management regimes have apparently resulted in an increase in plankton blooms, sponge and seagrass die-offs, and fish kills in Florida Bay, which adjoins the Sanctuary.

The Sanctuary addresses these threats using a variety of management programs and by applying regulations that address direct and indirect impacts to coral reef resources. In addition, a network of 24 fully protected ("no-take") zones, which cover approximately 6% of the Sanctuary but protect 65% of shallow bank reef habitats and 10% of coral resources overall, were implemented in 1997 (23 zones) and 2001 (Tortugas Ecological Reserve) to preserve specific areas more completely. Recent, dramatic declines in reef resources highlight the importance of monitoring both status and trends of habitats Sanctuary-wide and changes within the fully protected zones. In addition, empirical cause-and-effect studies are critical to shed light on additional management tactics that will alleviate and improve overall ecosystem health.

To monitor changes occurring in the marine environment of the Florida Keys, the Sanctuary has implemented a comprehensive monitoring program. The objectives of the monitoring program are to establish a reference condition for biological communities and water quality conditions within the Sanctuary. A research program directed at ascertaining cause-and-effect linkages complements monitoring. In this way, research and monitoring ensure the effective implementation and evaluation of management strategies using the best available scientific information.

Many groups, including local, state, and federal agencies, public and private universities, environmental organizations, and trained volunteers, conduct monitoring. The Sanctuary facilitates and coordinates partnerships with these groups, prioritizes activities, and disseminates relevant findings to the scientific community and to the public.

Monitoring within the Sanctuary occurs at two scales. Comprehensive, long-term monitoring is conducted through the Water Quality Protection Program (WQPP) funded by the U.S. Environmental Protection Agency (EPA), and recently, NOAA, the Florida Department of

Environmental Protection, Monroe County/Tourism Development Council, and the Sanctuary Friends of the Florida Keys. The WQPP began in 1994 and consists of status and trends monitoring of three components: water quality, coral reefs and hard-bottom communities, and seagrasses. Sanctuary-wide status and trends monitoring is designed to detect large-scale ecosystem changes associated with Everglades restoration and other regional-scale phenomena.

The second scale is associated with the Sanctuary's 24 fully protected marine zones, which are monitored through the Marine Zone Monitoring Program (MZMP). The goal of this program is to determine whether the zones are effective in protecting marine biodiversity and enhancing human values related to the Sanctuary. Measures of effectiveness include benthic community composition and coral population dynamics, abundance and size of fish and invertebrates, and economic and aesthetic values of the Sanctuary to its users and their compliance with regulations. The MZMP includes monitoring changes in ecosystem structure (size and number of invertebrates, fish, corals, and other organisms) and processes (such as coral recruitment and juvenile coral mortality). Human uses and perceptions of zoned areas are also being tracked. In essence, the MZMP is "nested" within Sanctuary-wide status and trends monitoring.

This report presents results from six-seven years of status and trends monitoring under the Water Quality Protection Program and four years of data from the Zone Monitoring Program. It starts with a description of circulation and exchange of South Florida coastal waters. Sanctuary-wide status and trends monitoring of water quality, seagrasses, and coral reef communities are presented next. A special program that tracks marine occurrences throughout the Sanctuary, the Marine Ecosystem Event Response and Assessment Project, is reviewed next. Individual abstracts that report results from the Zone Monitoring Program follow, grouped by topical area (coral reefs and benthic communities, fish populations, and spiny lobster and queen conch). Two reports on partnerships between the FKNMS and NOAA National Centers for Coastal Ocean Science address a Cellular Diagnostic System using corals and a study of disturbance and recovery dynamics of seagrass-coral banks. This year's annual report concludes with two studies of wastewater-derived nutrients in Florida Keys ground water. The *Sanctuary Monitoring Report 2000* is also available in downloadable format (.pdf) from the FKNMS website at http://floridakeys.noaa.gov/research_monitoring/welcome.html. We look forward to reporting future years' results and welcome your comments.

Circulation and Exchange of Florida Bay and South Florida Coastal Waters

Interdisciplinary Coastal Ocean Observations in the Florida Keys National Marine Sanctuary with Real-time Data Links

Elizabeth Johns and Peter B. Ortner (Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, FL)
Thomas N. Lee (Rosenstiel School of Marine and Atmospheric Science [RSMAS], University of Miami, Miami, FL)

Introduction

The coastal waters of the Florida Keys National Marine Sanctuary (FKNMS), surrounding the Florida Keys and the Dry Tortugas, are located in the transition region of the Loop Current and the Florida Current. The Dry Tortugas play a dynamic role in supporting regional marine ecosystems. Larvae that are spawned from adult populations in the Tortugas are spread throughout the Keys and south Florida by a persistent system of currents and eddies that provide the retention and current pathways necessary for successful recruitment of both local and more-distant recruits, with larval stages ranging from hours for some coral species to up to a year for spiny lobster. In addition, upwellings and convergences of the current systems provide frontal regions with concentrated food supplies that increase larval growth rates.

The well-known snapper spawning grounds of the Dry Tortugas are located adjacent to a persistent recirculation feature known as the Tortugas Gyre (Fig. 1), which provides an important mechanism for larval retention and distribution throughout the Florida Reef Tract as the gyre moves slowly west (Lee et al. 2002).

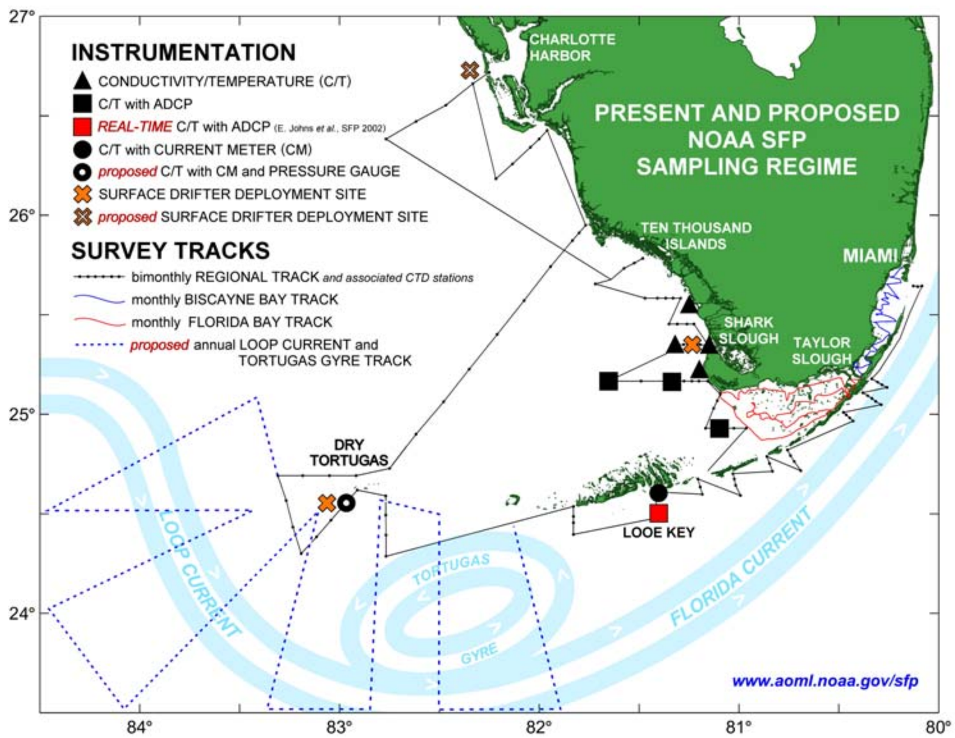


Figure 1. Instrumentation and survey tracks for present research program.

The protected spawning grounds of the Dry Tortugas are also affected by their proximity to the onshore edge of the Loop Current, which can deliver potentially harmful waters from remote land-based sources. A well-documented example of this occurred in 1993, when Mississippi River flood waters could be traced both in situ and by satellite as they were transported along the edge of the Loop Current, past the Dry Tortugas and the Florida Keys, and up the southeast U.S. coastline as far north as the Carolinas (Ortner et al. 1995).

Coral reefs of the FKNMS are subject to intrusions of potentially harmful waters from Florida Bay and the Southwest Florida Shelf because of their open connection to the Bay through Lower and Middle Keys passages. Surface drifters deployed on the southwestern Florida coast near the Shark River illustrate typical seasonal flow patterns (Fig. 2). Typically during the wet season (summer/fall), in response to prevailing winds, drifters tend to follow a westward path toward the Tortugas before entrainment in the Loop Current. During the dry season (winter/spring), drifters tend to travel southward across western Florida Bay and exit through passages of the Middle Keys. Subsequently drifters often remain in Hawk Channel near the reefs for several months, while at other times they reach the Florida Current and are quickly swept out of the area.

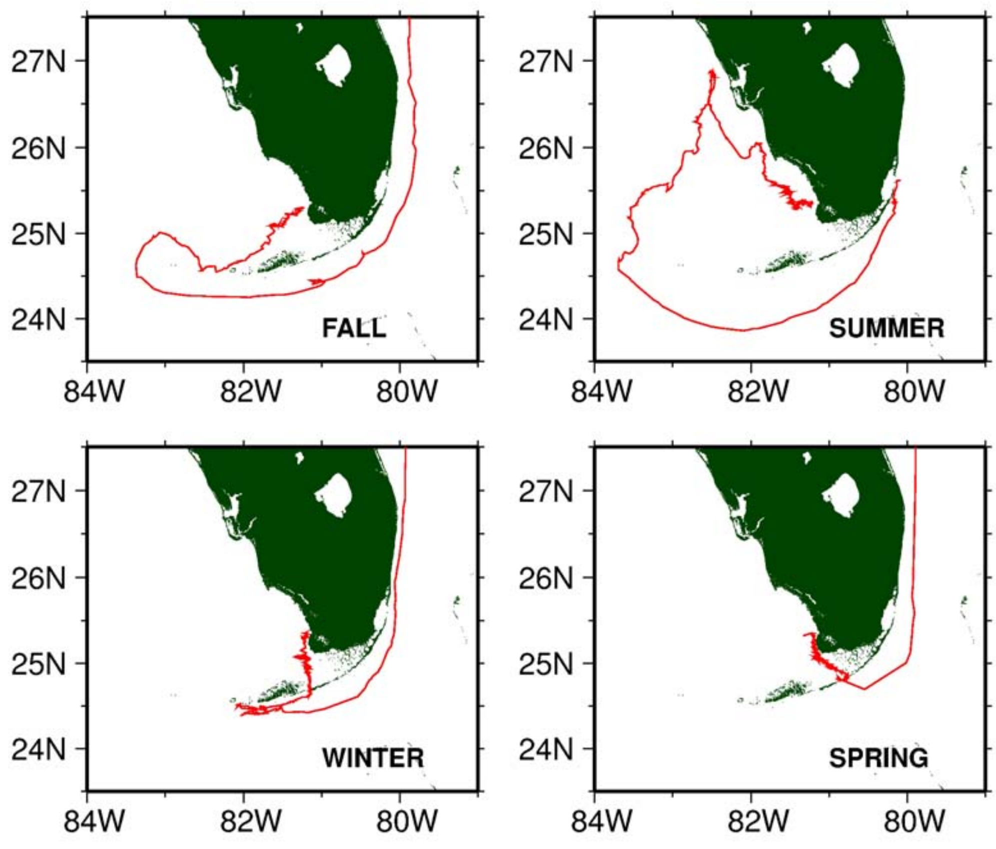


Figure 2. Representative seasonal satellite-tracked surface drifter trajectories (from Lee et al. 2002).

Keys passage outflow events occur sporadically, on time scales of days to weeks. Episodes of hypersalinity in Florida Bay, high turbidity, elevated nutrients, and harmful algal blooms such as red tides on the Southwest Florida Shelf can affect the health of reefs when these waters exit the

Bay. Because Florida Bay nutrient concentrations and turbidity are typically high compared to the oligotrophic conditions found offshore, the intrusions of Bay waters are thought to represent a potential threat to the health of the Florida Reef Tract (Porter et al. 1999).

Given such event-dominated variability, it is critical to resource management of the FKNMS and to the research community in general that these sustained, long-term, intrinsically linked current systems be measured continuously and the data made available in real-time wherever possible. Such information is needed to determine how current systems interact and transport materials between regions and what the potential ecological consequences may be. The value of real-time observations in the complex and interlinked marine systems of the south Florida region has already been shown during recent occurrences such as the "blackwater" event in winter 2002, the severe and persistent red tide bloom on the West Florida Shelf in spring 2003, and most recently by the transport of Mississippi River water into the FKNMS during May and June 2003. These data are also essential for the development, verification, and validation of numerical models being developed for Florida Bay and the surrounding coastal waters under the auspices of Florida Bay/Florida Keys Feasibility Study of the Comprehensive Everglades Restoration Plan.

Goals

The underlying goals of this research, funded by NOAA's South Florida Program (SFP), are to obtain greater insight into the complex, coupled ecosystems of south Florida coastal waters, and to provide scientific support for resource managers of the FKNMS. Specifically these include the following:

- Observe and understand circulation in and around the FKNMS on tidal to interannual time scales.
- Observe and understand the role of the Loop Current in long-term variations of flow between the Gulf of Mexico and the Atlantic Ocean.
- Observe and understand the causes of physical/chemical/biological "event scale" variability.

The operational objectives of the research are to provide data necessary to address the above scientific goals, and to provide specific critical information needed by resource managers of the FKNMS for timely decision-making.

Methods

The measurement program in 2002-2003 continued the same basic elements used in previous years: bimonthly interdisciplinary shipboard surveys over the entire south Florida coastal system and detailed monthly interdisciplinary surveys of the interior of Florida Bay; satellite-tracked surface drifter releases at the mouth of the Shark River; and in situ moored measurements on the Southwest Florida Shelf and in the FKNMS. The geographic scope of the monthly surveys was expanded in 2002-2003 to include Biscayne Bay. In addition, a new one-day interdisciplinary hydrographic survey was added to the bimonthly surveys in the coastal waters surrounding the Dry Tortugas, and satellite-tracked surface drifter releases were initiated there in the vicinity of Riley's Hump, an important larval spawning region (Fig. 1).

The bimonthly interdisciplinary surveys are conducted aboard the University of Miami's research vessel *F. G. Walton Smith*, and the high-resolution monthly interdisciplinary surveys of

Florida and Biscayne Bays are conducted aboard the smaller research catamaran the *Virginia K* (Fig. 3).

Figure 3. Research vessels used for the bimonthly interdisciplinary cruises aboard the R/V *F. G. Walton Smith* (left panel) and monthly cruises aboard the R/V *Virginia K* (right panel) along the cruise tracks shown in Figure 1.

Along their ship tracks both research vessels continuously measure salinity, temperature, transmittance, chlorophyll_a (chl_a), and chromophoric dissolved organic matter (CDOM) fluorescence, and take surface water samples for phytoplankton pigments, cell counts, total suspended solids, and nutrient analyses. On station, both vessels obtain conductivity-temperature-depth (CTD) profiles, light transmission observations, and vertical profiles of chl_a fluorescence. There are 16 stations regularly occupied in Biscayne Bay, 40 stations in Florida Bay, and 99 stations in the surrounding coastal waters of the FKNMS and the Southwest Florida Shelf. Rosette or bottle casts are conducted for chemical and biological analyses and, at a subset of the stations, net tows for zooplankton are also obtained. In addition, both vessels are equipped with Acoustic Doppler Current Profilers (ADCP) that operate whenever conditions (primarily water depth and sea state) permit, yielding continuous observations of upper water column currents.

During the bimonthly cruises, surface drifters are deployed in the vicinity of the Shark River mouth and more recently also in the Dry Tortugas near Riley's Hump. These drifters are approximately 1 m tall, and are ballasted to float low in the water column. They are equipped with "sails" to allow the drifters to move with the water. The drifters are tracked by ARGOS satellite, and the series of fixes used to compute their speed and direction. Data from the satellite-tracked surface drifters (example shown in Fig. 4) are obtained in real-time and posted on NOAA's South Florida Program (SFP) web site at www.aoml.noaa.gov/sfp.

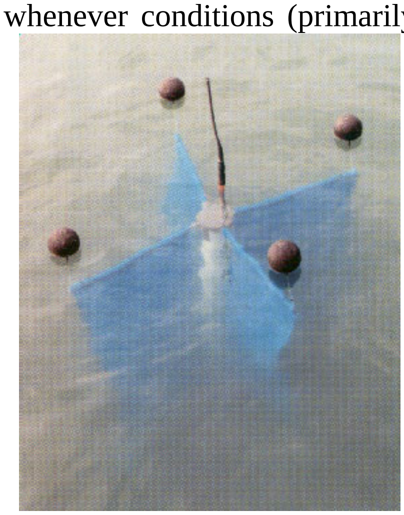


Figure 4. Surface drifter just after deployment.

Moored instruments are maintained in an array off the southwestern Florida coast and at the seaward edge of the reef tract at Looe Key, measuring temperature, salinity, and currents (Fig. 1). The Looe Key site has recently been upgraded to include real-time satellite communications for transmitting data to AOML. Additional sites in the Seven-Mile Bridge and Long Key Channelsare planned, and real-time communications and web-based data presentation methods are under development. This real-time observational network has been designed specifically as an early warning system for the FKNMS for intrusions of foreign water masses that could degrade FKNMS water quality or contain harmful algal blooms.

Findings to Date

Hydrographic Surveys

Variability in salinity, chlorophyll, and light transmittance occurs on a wide range of temporal and spatial scales, in response to both natural forcing such as wet/dry season precipitation and evaporation patterns and the interannual "El Niño" climate signal, as well as anthropogenic forcing such as water management practices in the south Florida canal system. Some recent examples of surface salinity variability are shown in Figures 5, 6, and 7. The full time series of surface property maps that have resulted from the bimonthly and monthly surveys are posted under Research Results on the SFP program web site at www.aoml.noaa.gov/sfp.

Figure 5 shows a contour map of surface salinity from data collected during a typical bimonthly survey of south Florida coastal waters. Data from the October 17-18 2002 monthly survey of Florida Bay have been incorporated into this map. While offshore waters of the Gulf of Mexico and the Florida Keys are relatively salty (35-36), the rainy season precipitation pattern has produced relatively freshwater discharges from rivers along the southwestern Florida coastline (30-33), and the salinity along the northern coastline of Florida Bay is fresher still (less than 25).

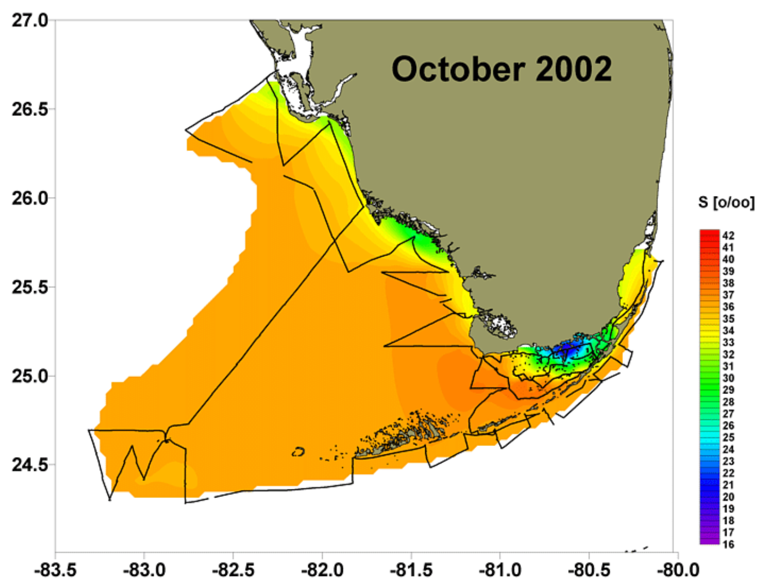


Figure 5. Surface salinity from the bimonthly cruise conducted during October 2002.

Figures 6 and 7 show contour maps of surface salinity from typical monthly surveys of Florida Bay and Biscayne Bay. The Florida Bay survey (Fig. 6) provides a closer look at the data also shown in Figure 5, showing the detailed cruise track that is designed to sample all accessible basins of Florida Bay over a two-day period. Most of the freshwater input at this time (October 17-18, 2002) is coming from the Taylor Slough area, in northeastern Florida Bay.

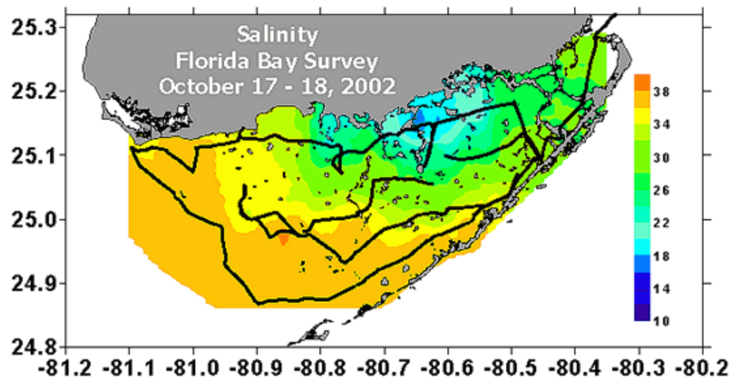
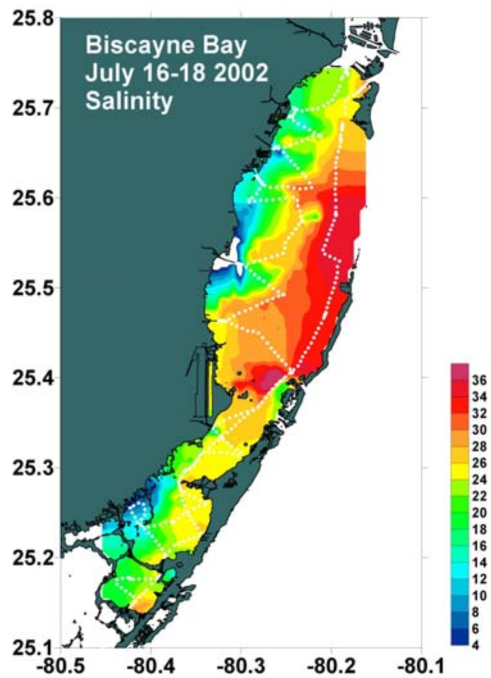


Figure 6 (above). Surface salinity in Florida Bay from monthly survey conducted on October 17-18, 2002.

Figure 7 (at right). Surface salinity in Biscayne Bay from monthly survey conducted on July 16-18, 2002.



The Biscayne Bay survey from July 16-18 2002 (Fig. 7) shows a typical wet season surface salinity pattern of high salinity (35-36) waters present along the western part of the Bay where there are open connections to the Atlantic Ocean, and very low salinity river and canal input (< 10) present at freshwater source locations along the northern shoreline of the Bay.

Surface Drifters

Satellite-tracked surface drifters can be used to track regional surface circulation patterns, which respond to large-scale forcing such as wind variability and sea level slopes. Some representative trajectories are shown below in Figures 8 and 9.

Figure 8 shows a drifter deployed near the mouth of the Shark River on December 10, 2003. This drifter moved slowly to the south until it ran aground just north of the Seven-Mile Bridge. This flow direction and speed, typical of the winter months, can carry harmful algal blooms such as red tides and black water, and riverine waters carrying high nitrate and phosphate loads, into close proximity to the waters of the FKNMS.

Figure 9 shows the trajectory of a drifter deployed in the Dry Tortugas on December 13, 2003. This pathway illustrates one of the perils that can potentially befall larval species, as the drifter almost immediately became entrained into the Loop Current/Florida Current/Gulf Stream and rapidly exited the area, reaching a latitude of 33^{o}N before becoming entrained in coastal currents of the Atlantic shelf.

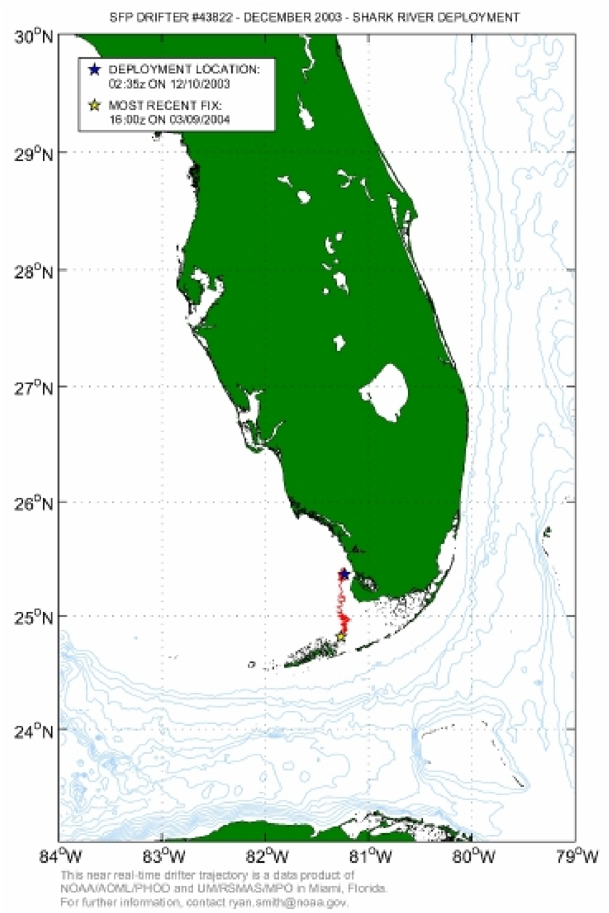


Figure 8. Surface drifter deployed on December 10, 2003, near the Shark River mouth.

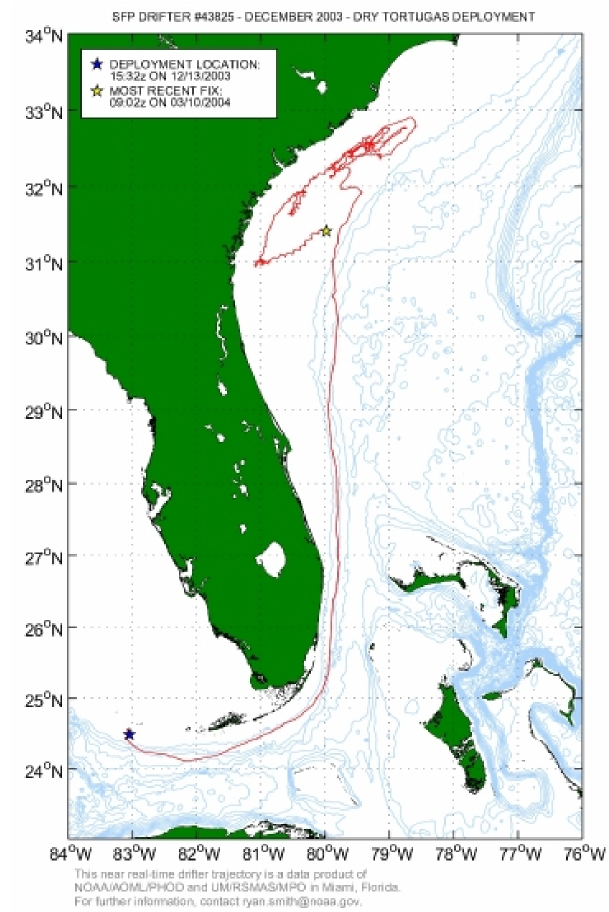


Figure 9. Surface drifter deployed on December 13, 2003, near Riley's Hump in the Dry Tortugas.

The Tortugas Gyre is a regional oceanographic feature that plays a particularly important role in larval transport and retention (Lee et al. 2002). This gyre, which is generally located to the south of the Dry Tortugas along the inshore front of the Loop Current, forms periodically over a period of weeks to months and then slowly drifts through the region until it is absorbed by the Florida Current offshore of the Keys. Figure 10 shows a satellite-tracked surface drifter that was deployed in the Tortugas in August 2002 during one of the bimonthly surveys. This

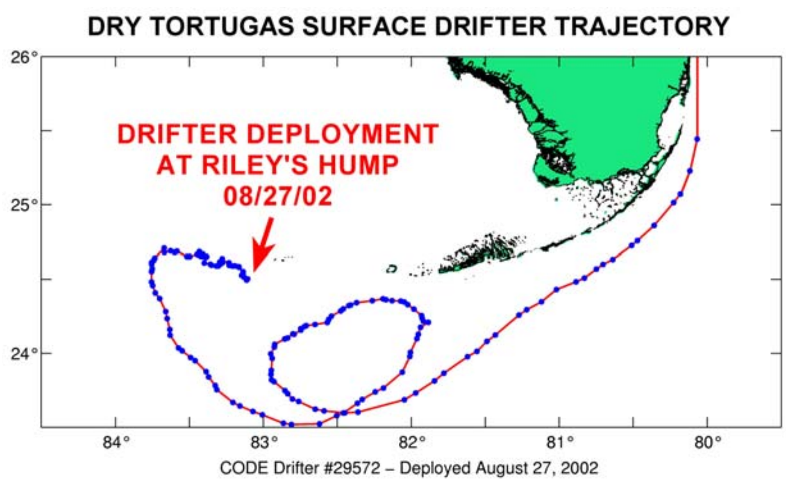


Figure 10. Trajectory of surface drifter deployed in the Dry Tortugas, August 2002.

drifter moved slowly to the northwest until it was entrained along the edge of the Loop Current, made one revolution around the Tortugas Gyre, and then exited the area via the Florida Current.

Florida Keys Passages

The Southwest Florida Shelf and the Atlantic side of the Florida Keys coastal zone are directly connected by passages between the islands of the Middle and Lower Keys. Movement of water between these regions depends on a combination of local wind-forced currents and gravity-driven transports through the passages, produced by cross-Key sea level differences on time scales of several days to weeks (Lee and Smith 2002; Smith and Lee 2003; Johns et al. 2003), which arise because of differences in physical characteristics (shape, orientation, and depth) of the shelf on either side of the Keys.

On long time scales, both the higher mean water level of the eastern Gulf of Mexico and variations in the strength and location of the Loop Current may have important influences on mean transports through Keys passages. The long-term mean volume transports through the primary channels of the Middle Keys are –55 m^3/s each for Channels 2 and 5, –260 m^3/s for Long Key Channel, and –370 m^3/s for the Seven-Mile Bridge Channel, where negative mean values represent outflows from Florida Bay (Fig. 11; Lee and Smith 2002). The Seven-Mile Bridge Channel accounts for about 50% of the flow, Long Key Channel for about 35%, and Channels 2 and 5 account for about 7% each. This southeastward mean flow provides a mechanism for direct transport from western Florida Bay, where the waters are known to undergo large changes in water quality, to the coral reefs of the FKNMS.

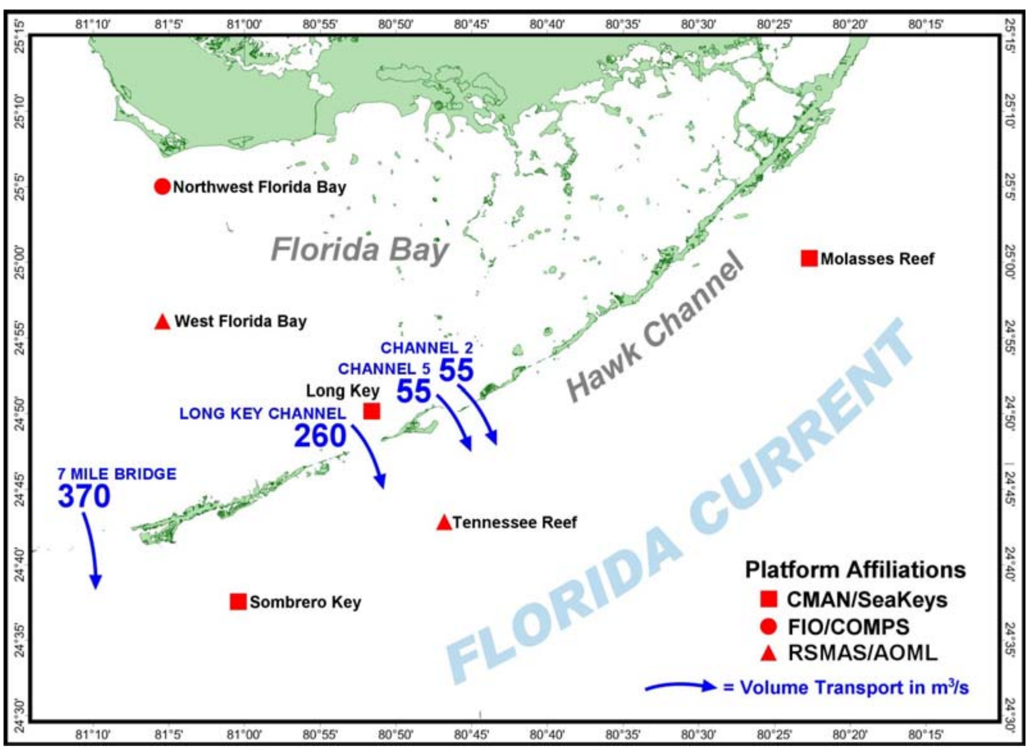


Figure 11. Long-term mean volume transport through the Keys passages.

Lee and Smith (2002) also found that there was an annual cycle of cross-Key sea level slopes and transports through Keys passages that had a direct relationship to the annual cycle of local wind forcing. Maximum subtidal outflows from Florida Bay occurred in the winter and spring following cold fronts, when winds from the west are more common. Minimum outflows and even flow reversals occurred in the fall when wind directions from the northeast and east prevail, causing several-day periods of inflow to Florida Bay from the Atlantic.

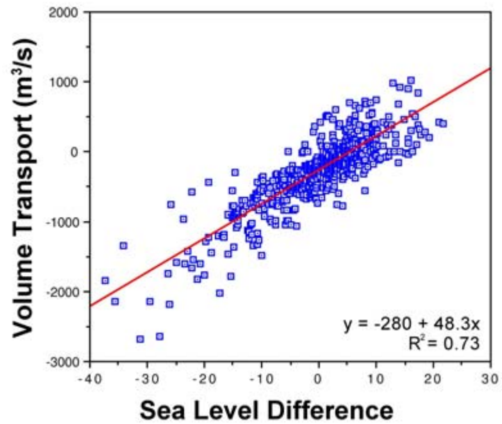


Figure 12. Volume transport vs. sea level difference (Tennessee Reef minus West Florida Bay).

Sea level differences across the Middle Keys are highly correlated with subtidal volume transport through Keys passages, as clearly shown from the comparison of bottom pressure measurements at Tennessee Reef and western Florida Bay, and shipboard volume transport observations (Fig. 12). Although reversing tidal currents dominate flows through Keys passages on shorter time scales, local wind forcing is the primary cause of this lower-frequency transport variability.

This situation is illustrated in another way in Figure 13 from Melo et al. (2003), using the network of tide gauges maintained by Everglades National Park (data courtesy of D. Smith). Winds blowing into Florida Bay from the west cause a gravity-driven outflow from Florida Bay due to a greater set-up of sea level in western Florida Bay than on the Atlantic side of the Keys (Fig. 13a). This is reversed for easterly winds, which push water out of Florida Bay and pile water up against the eastern margin of the Bay (Fig. 13b).

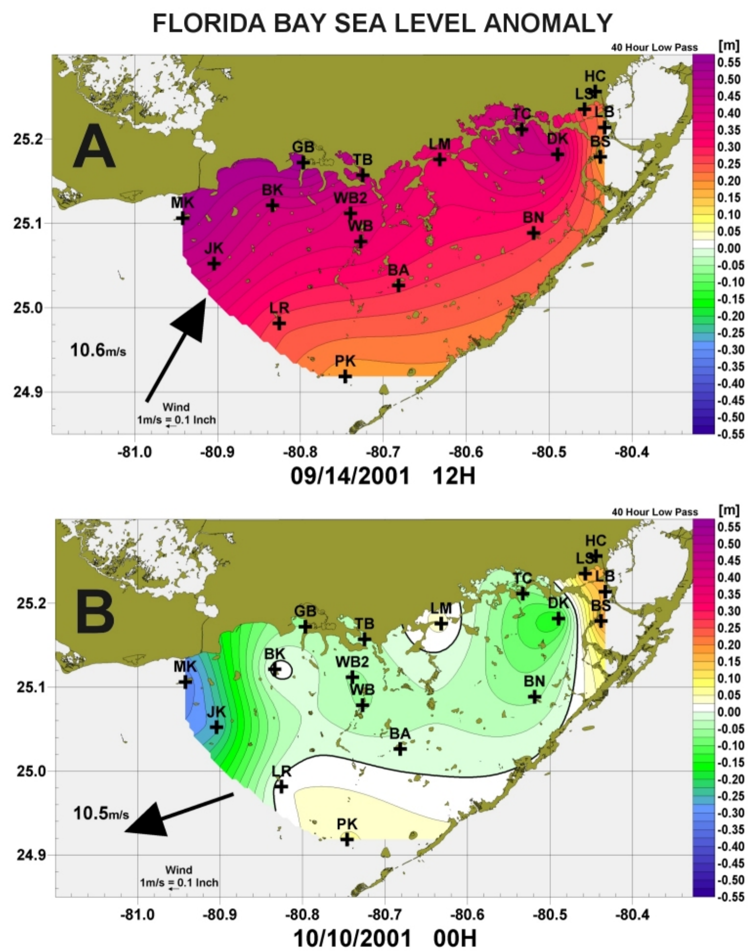


Figure 13. Sea level height in Florida Bay and its response to directional wind forcing (Melo et al. 2003).

These results have advanced our understanding of causes of circulation and water quality variability in Keys passages and the FKNMS. We are in the process of developing a real-time system for monitoring flow through major Keys passages. In this system, real-time sea level differences would be obtained from the CMAN/SEAKEYS stations at Long Key and Sombrero Key (Fig. 11). After an initial calibration phase involving intensive shipboard and moored data collection (an effort that is presently underway), the CMAN sea level data alone should provide calibrated volume transport information continuously and in real-time.

We used a prediction of outflow from Florida Bay to the reef made on the basis of the sea level difference to stage opportunistic field work during April 2003, which confirmed the outflow. Examination of SeaWiFS satellite images for this period showed that the outflow was unusually high in chlorophyll, and samples were obtained to ground-truth and calibrate the satellite data.

In addition to the Keys passages real-time volume transport observations, the Seven-Mile Bridge has recently been instrumented with conductivity-temperature (C/T) sensors, and soon will be instrumented with a fluorometer and a transmissometer. These instruments will be linked to AOML via cell phone to provide continuous real-time water quality information that, combined with the volume transport estimated from the sea level data, will yield a simultaneous record of volume transport and water quality from Florida Bay into Hawk Channel and the reef tract. Continuous water quality information will help to ground-truth satellite imagery and will be used to alert event-response teams who can provide rapid, targeted sampling in Keys passages, Hawk Channel, and coral reefs of the FKNMS.

Oceanographic Events

Some of the most dramatic oceanographic "events" that can affect marine environments of South Florida coastal waters happen only sporadically. In this context, the term "event" includes intermittent/irregular forcing functions such as remote intrusions; transient eddies and water releases; periodically enhanced outflows carrying high chlorophyll or nutrient levels from Florida Bay to the FKNMS reef tract; black water; red tides; and meteorological occurrences such as tropical storms. To adequately sample such events requires both the capability of near real-time recognition of these events, and the flexibility to rapidly stage targeted field sampling.

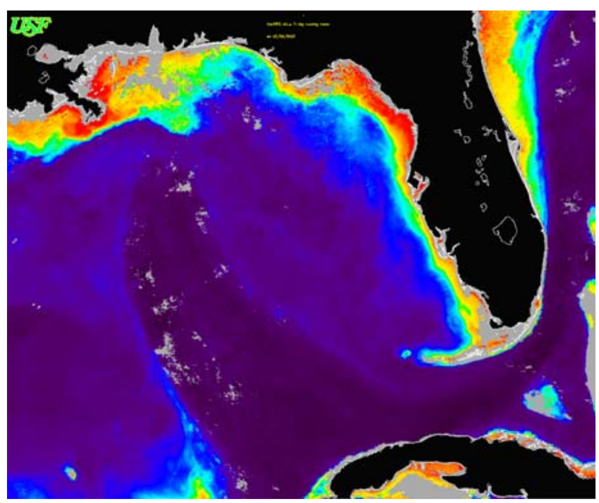


Figure 14. Satellite-derived ocean color image of the Loop Current/Mississippi River interaction, courtesy of C. Hu of the University of South Florida.

For example, in May-June 2003 Mississippi River water was transported to the Dry Tortugas region by the Loop Current as noted by satellite color images (Fig. 14) and HYCOM regional model results (Kourafalou 2003). This event was similar to a 1993 event documented by Ortner et al. (1995). Early notice enabled us to sample the properties of the anomalous water mass and to alert FKNMS managers and other interested researchers weeks prior to the Dry Tortugas incursion.

The advantage of using satellite data was clearly demonstrated during the spring 2002 "blackwater" event. During this episode, a large area of discolored water was noticed in the region of the Southwest Florida Shelf on SeaWiFs satellite color imagery. The dark area persisted for several months and moved slowly with the prevailing currents (SWFDOG 2002; Hu et al. 2003). We tracked what ultimately turned out to be an unusual diatom bloom with surface drifters deployed along the Southwest Florida Shelf, and staged additional event-sampling fieldwork in the FKNMS that proved helpful in confirming what was causing the discolored water. The drifter and satellite data were consistent (Fig. 15), and provided valuable information for studying the origin and fate of the anomalous water mass.

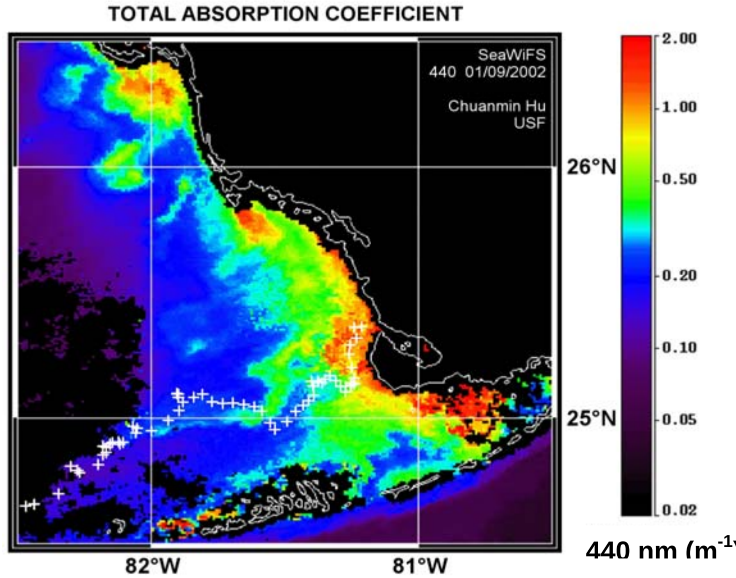


Figure 15. Total absorption at 440 nm (m^{-1}) from SeaWiFS, with superimposed surface drifter trajectory (+), January 2002 from Hu et al. (2003).

During the spring of 2003 a severe red tide bloom affected the Southwest Florida Shelf. While we were in the field conducting our regular April 2003 bimonthly survey we adapted our sampling strategy to aid the Florida Fish and Wildlife Research Institute in surveying the red tide bloom, and we deployed a satellite-tracked surface drifter in the bloom center. The trajectory indicated a slow circulation to the north along the mangrove shoreline that explained the concentration of the bloom around Cape Romano. The direction and slow speed of the currents may have contributed to the severity and longevity of this particular red tide episode.

Looe Key Mooring

The Looe Key long-term mooring site is located just seaward of the reef at 24°32.55'N, 81°24.13'W, in a water depth of approximately 22 m. This mooring (Fig. 16), a rigid spar buoy instrumented with temperature and conductivity sensors and a bottom-mounted Acoustic Doppler Current Profiler (ADCP) to measure currents, has recently been equipped with real-time communications. Data are communicated hourly to AOML using an MSAT satellite link, and are automatically posted onto the project web page at *www.looekeydata.net*, which also is accessible through the SFP program web site.

Figure 16. Looe Key real-time spar buoy.

Current and temperature measurements have been maintained at the Looe Key site for the past 13 years under various funding sources, making this the longest nearly continuous current measurement site in the Florida Keys. The site is important not only because of its close proximity to the popular Looe Key recreational diving area, but also because of its sensitive location downstream of Middle Keys passages where it is subject to transient outflows from western Florida Bay. Previous analyses of long-term current and temperature records from this site have shown the strong influence of Tortugas eddies as they move eastward through the region, as well as the influence of local wind forcing (Lee et al. 1992, 2002). Mean flows at this location are toward the west due to these combined forces, with a strong alongshore tendency. To understand longer-term ecosystem responses to this oceanographic and meteorological variability and to identify physical processes driving transient events and their frequency of occurrence requires continuation of these long-term measurements.

Figures 17a and 17b show salinity and temperature records from the Looe Key mooring for the period December 2002 to June 2003. The variability is striking and coherent, and is related not only to seasonal heating and cooling cycles but also to the location of Looe Key near the edge of the Florida Current. Periodically, warmer waters of that current are noticeable when it meanders onshore; transient outflow events from Florida Bay also can occur. Figure 17c shows surface currents recorded by the Looe Key Acoustic Doppler Current Profiler (ADCP). The variability is again striking, and is related to the location of the mooring site near the edge of the Florida Current. The predominant currents are oriented alongshore, alternately to the northwest or to the southeast, as the site is subject either to strong eastward Florida Current flow as it meanders onshore, or to the westward flows associated with eddies located along the current front (Fig. 1).

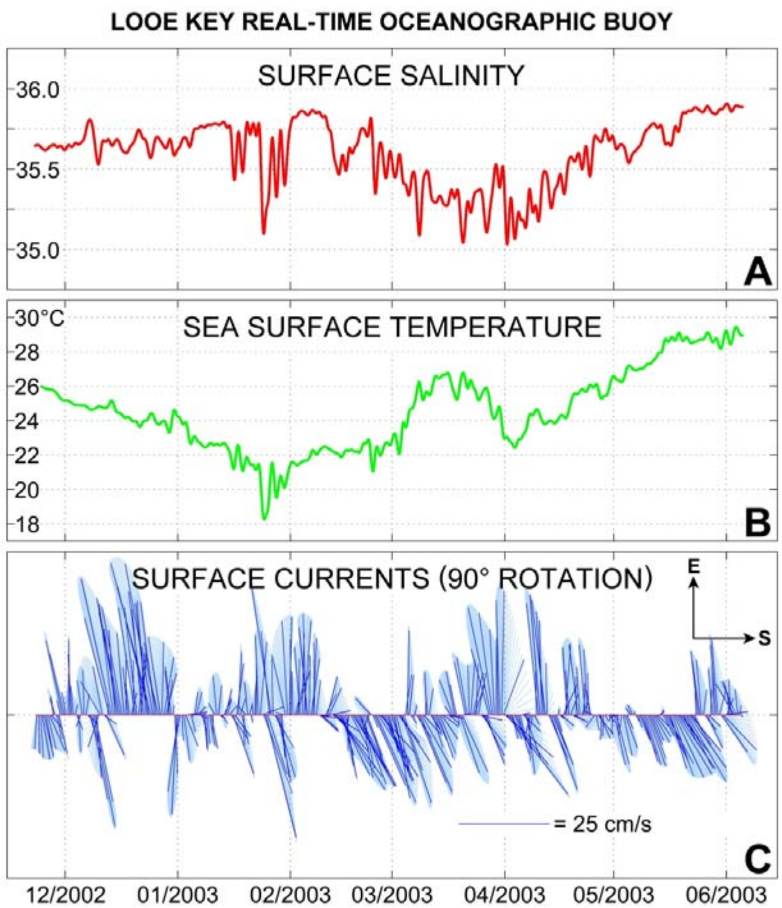


Figure 17. Time series of salinity (a), temperature (b), and currents (c) from Looe Key during the period December 2002 to June 2003.

Tortugas Region

A review of the state of knowledge of the currents and hydrography of the Tortugas region can be found in "Site Characterization for the Tortugas Region: Physical Oceanography and Recruitment" by Lee et al., posted at the FKNMS web site. This reference describes the oceanographic characteristics of the Tortugas using a synthesis of results from the literature as well as recent and ongoing studies. Particular emphasis is placed on the influence of physical processes on larval recruitment from local and remote sources, and the interconnectivity of the major regional current systems including the Loop Current, the Tortugas Gyre, and the wind-driven currents of both the Florida Keys coastal zone and the West Florida Shelf.

Given the recent awareness of the uniqueness and value of this nearly pristine coral reef ecosystem, which in fact helped lead to the creation in July 2001 of the Tortugas Ecological Reserve by the FKNMS to ensure its future protection, the need for a more complete understanding of the oceanography of the Dry Tortugas is pressing. The long-term monitoring program of bimonthly regional cruises recently added interdisciplinary, regional shipboard surveys of the Tortugas as well as regular satellite-tracked drifter releases at Riley's Hump, an important snapper spawning ground (Fig. 18).

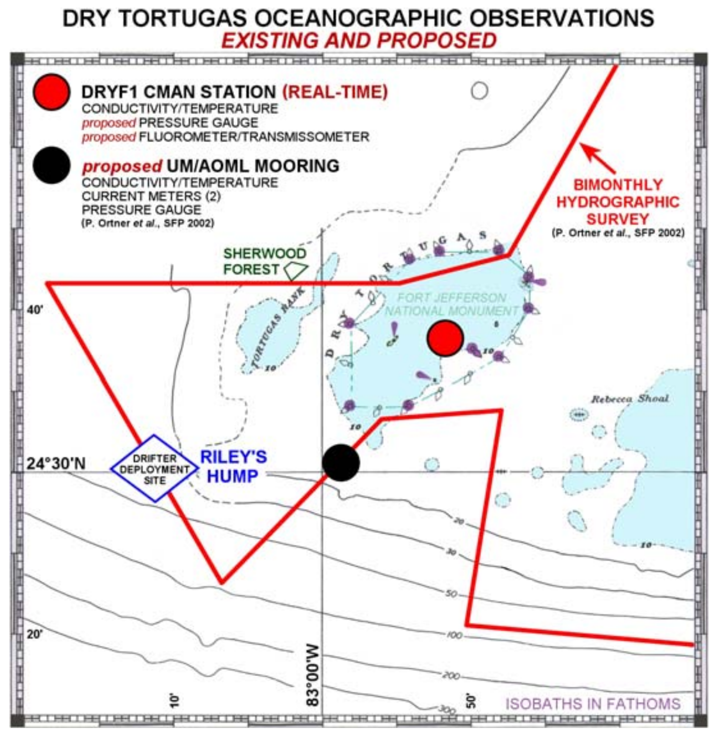


Figure 18. Existing and proposed oceanographic observations in the Dry Tortugas.

Future Plans

At this time our research in the FKNMS has been funded as part of SFP 2004 by NOAA's Coastal Ocean Program through March 2006. The bimonthly surveys aboard the R/V *F. G. Walton Smith* will be continued, as will the monthly surveys of Florida Bay and Biscayne Bay aboard the R/V *Virginia K.* Drifters will continue to be deployed in the Shark River mouth and the Dry Tortugas, and a third drifter deployment site will be added to the north near Charlotte Harbor.

The real-time effort will continue, with an emphasis on adding additional instrumentation to provide water quality information (i.e., fluorometer and transmissometer) as well as standard physical oceanographic parameters such as temperature, salinity, and currents. We are looking into the possibility of adding continuous real-time wave height observations to our suite of instruments located near coral reefs. We are also planning to expand the array, with stations in the planning stages for the Bear Cut Bridge near Virginia Key Beach in Biscayne Bay, and at the NOAA/National Undersea Research Center/University of North Carolina at Wilmington underwater laboratory, *Aquarius*, located at Conch Reef offshore of Key Largo.

Event sampling will continue to be a high priority, as will continued coordination with other federal, state, and local organizations to gain data that will lead to improved understanding of the causes and effects of marine environmental phenomena such as red tides, black water, and other events that require rapid staging of observational efforts.

References

Hu, C., K.E. Hackett, M.K. Callahan, S. Andréfouët, J.L. Wheaton, J.W. Porter, and F.E. Müller-Karger. 2003. The 2002 ocean color anomaly in the Florida Bight: a cause of local coral reef decline? Geophys. Res. Lett. 30(3): 1151.

Johns, E., T.N. Lee, P.B. Ortner, R.H. Smith, C.R. Kelble, N. Melo, S. Cummings, Jr., E. Williams, and J.C. Hendee. 2003. New interdisciplinary oceanographic observations in the coastal waters adjacent to Florida Bay. Proceedings, Joint Conference on the Science and Restoration of the Greater Everglades and Florida Bay Ecosystem. April 13-18, 2003, Palm Harbor, FL.

Kourafalou, 2003. http://hycom.rsmas.miami.edu/kourafalou/Alert.pdf

Lee, T.N., C. Rooth, E. Williams, M. McGowan, A. Szmant, and M. E. Clarke. 1992. Influence of Florida Current, gyres and wind driven circulation on transport of larvae and recruitment in the Florida Keys coral reefs. Cont. Shelf Res. 12:971-1002.

Lee, T.N., E. Johns, W.D. Wilson, E. Williams, and N. Smith. 2002. Transport processes linking South Florida coastal ecosystems. Pages 309-342 *in*: J.W. Porter and K.G. Porter, eds. The Everglades, Florida Bay, and coral reefs of the Florida Keys: an ecosystem sourcebook. CRC Press, Boca Raton, FL.

Lee, T.N., and N. P. Smith. 2002. Volume transport variability through the Florida Keys tidal channels. Cont. Shelf Res. 22:1361-1377.

Melo, N., T.N. Lee, E. Williams, D. Smith, M. Framinan, R.H. Smith, and E. Johns. 2003. A movie of Florida Bay sea level response to local wind forcing. Proceedings, Joint Conference on the Science and Restoration of the Greater Everglades and Florida Bay Ecosystem. April 13-18, 2003, Palm Harbor, FL.

Ortner, P.B., T.N. Lee, P.J. Milne, R.G. Zika, M.E. Clarke, G.P. Podestá, P.K. Swart, P.A. Tester, L.P. Atkinson, and W.R. Johnson. 1995**.** Mississippi River flood waters reached the Gulf Stream. J. Geophys. Res. Lett. 100: 13595-13602.

Porter, J.W., S.K. Lewis, and K.G. Porter. 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: a landscape hypothesis and a physiological test. Limnol. Oceanogr. 44: 941-949.

Smith, N.P., and T.N. Lee. 2003. Volume transports through tidal channels in the middle Florida Keys. J. Coast. Res. 19: 254-260.

South-West Florida Dark-Water Observations Group (SWFDWOG). 2002. Satellite images track “black water” event off Florida coast. Eos Trans. Amer. Geophys. Union 83: 281, 285.

Water Quality, Seagrass, Coral Reef, and Episodic Event Monitoring

Florida Keys National Marine Sanctuary Water Quality Monitoring Project

Ronald D. Jones and Joseph N. Boyer (Southeast Environmental Research Center [SERC], Florida International University, Miami, FL)

Goals

The Water Quality Monitoring Project for the Florida Keys National Marine Sanctuary (FKNMS) is part of the Water Quality Protection Program. The goal of this large-scale, long-term monitoring project is to assemble a holistic view of broad physical, chemical, and biological interactions occurring over the South Florida hydroscape. Water quality monitoring can be used as a tool for answering management questions and developing new scientific hypotheses, such as "Is water quality better or worse than it used to be?" This monitoring project, based on quarterly sample intervals, has revealed significant spatial trends in nutrients as described below, and we expect to see more trends in other variables as the database grows.

Methods

This project began in March 1995 and includes data collected from quarterly sampling events at 154 stations within the FKNMS, including the Dry Tortugas National Park. Since initiation we have added four sampling sites and adjusted six others to increase coverage in Sanctuary Preservation Areas and Ecological Reserves. Field parameters measured at each station include salinity, temperature, dissolved oxygen (DO), turbidity, in situ chlorophyll *a* fluorescence, and light attenuation (K_d). Water chemical variables measured at each station include the dissolved nutrients nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), and soluble reactive phosphate (SRP). Total unfiltered concentrations of organic nitrogen (TON), organic carbon (TOC), phosphorus (TP), and silicate ($Si(OH)_4$) are also measured. The monitored biological parameters included chlorophyll *a* (CHLA) and alkaline phosphatase activity (APA).

Findings to Date

We have found that water quality monitoring programs composed of many sampling stations situated across a diverse hydroscape are often difficult to interpret because of the "can't see the forest for the trees" problem. This makes it difficult to see the larger, regional picture or to determine associations among sites. In order to gain a better understanding of spatial patterns of water quality of the FKNMS, we attempted to reduce the complicated data matrix into fewer elements, which would provide robust estimates of condition and connection. To this end we developed an objective classification analysis (OCA) procedure, which grouped stations according to similarities in water quality.

The OCA we used was a multivariate statistical protocol, which used 12 water quality variables at each site as fingerprints that were then grouped according to similarity. The result was the deconvolution of 150 stations into eight clusters of stations with distinct water quality signatures (Fig. 1). We believe this is a more functional zonation of the FKNMS than a geographical one because it is driven by physical, chemical, and biological aspects of the water column.

The bulk of the stations fell into five clusters (1, 3, 5, 6, and 8), which described a gradient of water quality throughout the FKNMS. Although the differences among them were subtle, they were statistically significant. OCA allowed us to say that the overall nutrient gradient, from highest to lowest concentrations, was Cluster 8&1 > 5 > 6 > 3. Clusters 3, 6, and 5 were distributed widely throughout the Atlantic side of the Keys and Tortugas while Clusters 1 and 8

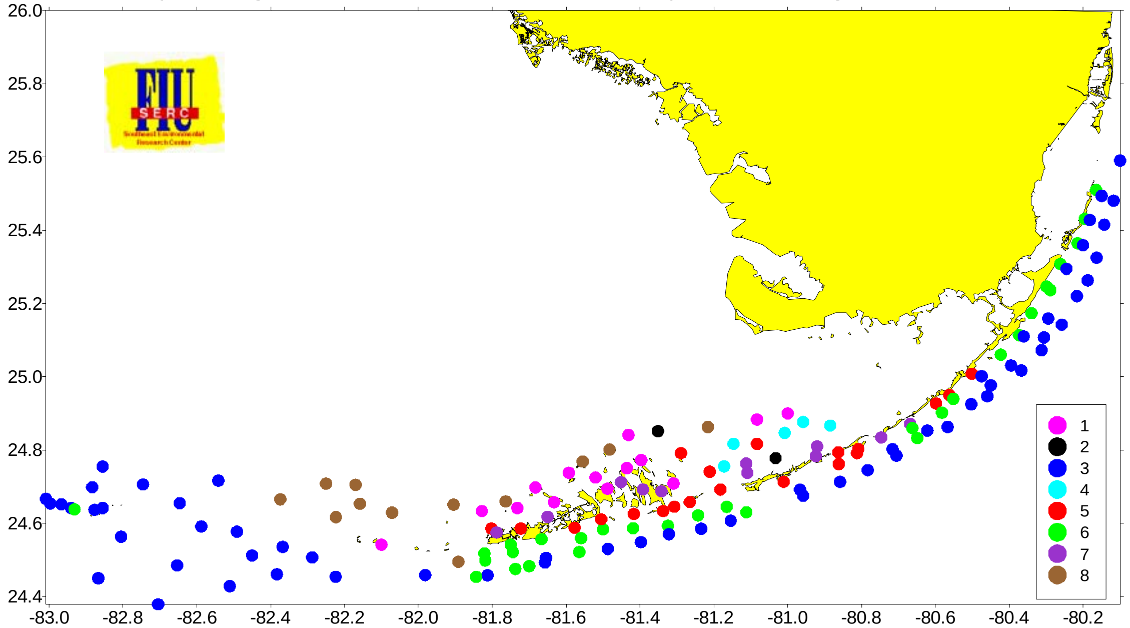


Figure 1. Sampling locations and cluster membership for all 154 sites in the FKNMS.

were present only on the Gulf side of the Keys. The stations in Cluster 3, located on the reef tract and Tortugas, had the lowest nutrient concentrations of all the groups (Fig. 2). This was followed by Clusters 6 and 5, which were driven mainly by increasing NO_3^- concentrations. Inshore stations of the less-inhabited Upper Keys exhibited lowest alongshore NO_3^- levels compared to the Middle and Lower Keys. Interestingly, NO_3^- concentrations in the single Tortugas transect were similar to those of reef tract sites in the Upper Keys, i.e., there was no inshore elevation of NO_3^- in the transect off uninhabited Loggerhead Key. We suggest that this source of NO_3^- in the Keys is due to shoreline development.

Cluster 1 was composed primarily of stations located within the Backcountry area north of the Lower Keys (Fig. 1). Along with Cluster 8, it was highest in TP and turbidity. Cluster 8 was made up of stations on the north side of the Backcountry extending west over the northern Marquesas and was highest in CHLA. This is the area most heavily influenced by advection of Southwest Florida Shelf waters.

Temporal analyses of water quality showed most variables were relatively consistent from year to year, with some showing seasonal excursions. The exception was increasing variability in TP concentrations throughout the region. This brings up an important point that, when looking at what are perceived to be local trends, we find that they seem to occur across the whole region but at more damped amplitudes. This spatial autocorrelation in water quality is an inherent property of highly interconnected systems such as coastal and estuarine ecosystems driven by similar hydrological and climatological forcings. Clearly, there have been large changes in FKNMS water quality over time, but no sustained monotonic trends have been observed. We must always keep in mind that trend analysis is limited to the window of observation; trends may change with additional data collection.

The large scale of this monitoring project has allowed us to assemble a much more holistic view of broad physical/chemical/biological interactions occurring over the South Florida hydroscape. Much information has been gained by inference from this type of data collection program: major nutrient sources have been confirmed, relative differences in geographical determinants of water quality have been demonstrated, and large-scale transport via circulation pathways has been elucidated. In addition, we have shown the importance of looking "outside the box" for questions asked within. Rather than thinking of water quality monitoring as being a static, non-scientific pursuit it should be viewed as a tool for answering management questions and developing new scientific hypotheses. We continue to maintain a website of the SERC water quality network (Florida Bay, Whitewater Bay, Biscayne Bay, Ten Thousand Islands, and Southwest Florida Shelf) displayed as downloadable contour maps, time-series graphs, and interpretive reports. Data from the FKNMS are integrated with the other parts of the monitoring network (http://serc.fiu.edu/wqmnetwork/).

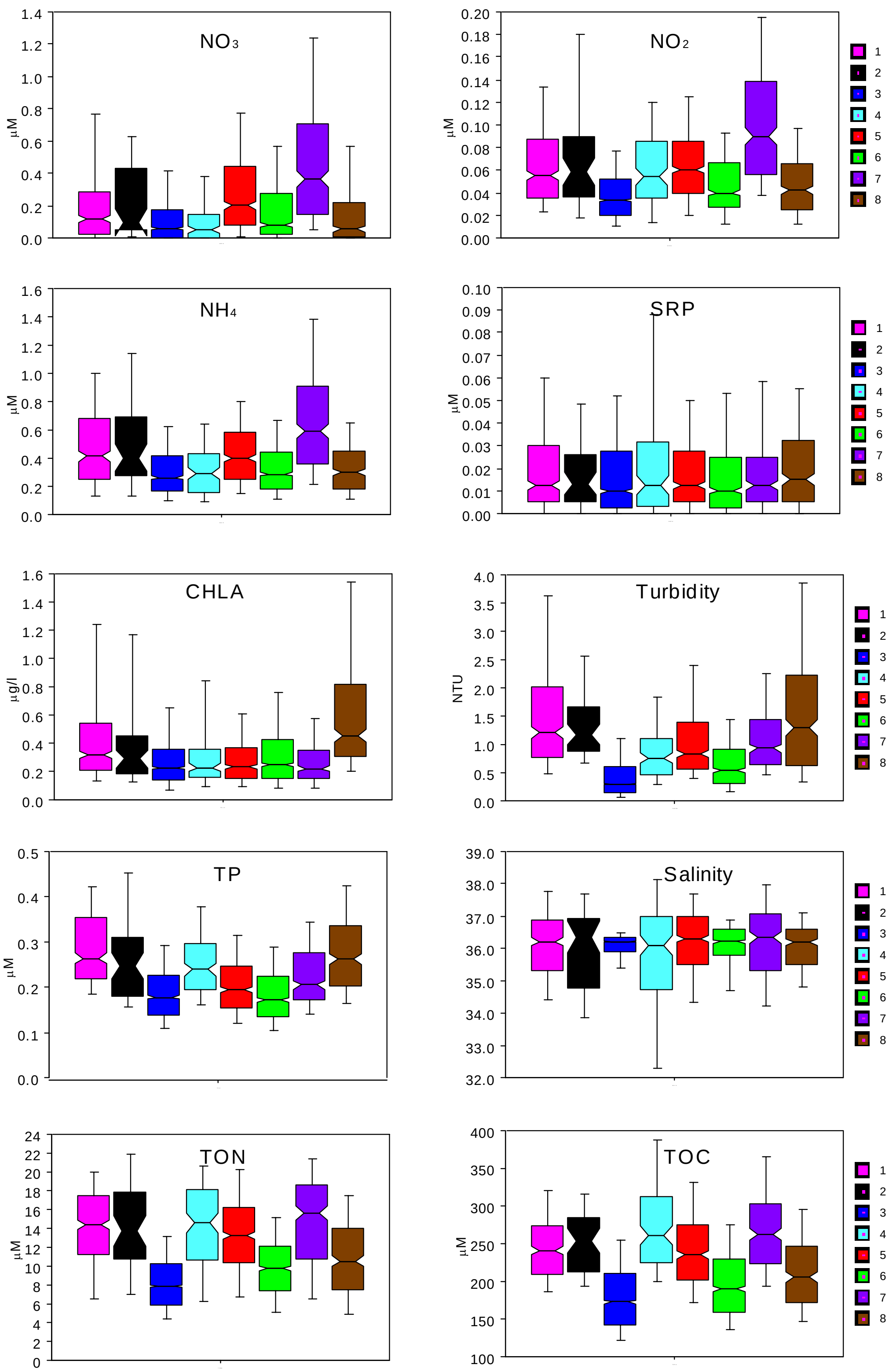


Figure 2. Median and range of variables stratified by cluster (see Fig. 1). Units are µM (nutrient and TOC concentrations), µg/L (CHLA concentration), Normal Turbidity Units (NTU; turbidity), and Practical Salinity Units (salinity).

Florida Bay Watch

Brad Rosov, The Nature Conservancy, Sugarloaf Key, FL.

Goals

Florida Bay Watch was a volunteer-driven program with a two-fold mission in Florida Bay and the Florida Keys: 1) to collect scientific information about the health and status of the Florida Bay ecosystem, and 2) to involve concerned citizens of the Keys in formulating solutions for the problems of Florida Bay. Through the Florida Bay Watch program, volunteers were trained in basic methods of sampling water quality, which they employed to collect water quality data and samples for one or more Florida Bay Watch projects. These projects were designed to augment studies conducted by scientists in public agencies and academic institutions.

Florida Bay Watch was a partnership. The Nature Conservancy (TNC), a private, non-profit conservation organization, was the managing partner, providing staff support and coordination for the Florida Bay Watch program. Part of the program's commitment to volunteers, scientists, and agencies that made the program possible was the presentation of results of various Florida Bay Watch projects and the dissemination of Florida Bay Watch data to interested parties.

Methods

Nearshore Fixed Stations

Water quality data were obtained from a series of fixed stations located throughout the Florida Keys. Sampling at some stations began as early as June 1994; the addition of new stations and discontinuation of others occurred over the course of the project (until 2002). Stations included plugged canals, open-ended canals, boat basins, and natural/unobstructed shorelines. Besides these obvious differences, sites varied in many aspects, including water depth, circulation and flushing rates, nearby vegetation, and type and number of adjacent On-Site Sewage Disposal Systems (OSDSs). Most volunteers sampled from docks, seawalls, or the shoreline.

Volunteers who routinely sampled at nearshore water quality stations were trained in basic methods of sampling water quality. Training included instruction on filling out data forms, techniques for calibrating field equipment, and emphasis on careful handling of water samples to ensure the integrity of the data. The TNC Marine Conservation Program Manager supervised a trained intern who periodically evaluated volunteers on the care and manner with which they sampled, and all data went through a quality-control check to identify possible sampling errors. A quality-assurance plan for this project was filed with the Region IV Water Management Division of the U.S. Environmental Protection Agency.

Volunteers were instructed to sample weekly at their station during a low tide. Data sets for most stations followed this routine, with some exceptions. The following information was recorded on a standardized data form: date, time, tide, Beaufort number for wind and sea state, wind direction, current strength, current direction, Secchi depth, time of Secchi reading, sea-surface temperature, specific gravity, sea surface salinity (from hydrometer tables), and rainfall in the last 24 hours. In addition, volunteers collected a water sample to be analyzed for total nitrogen (TN) and total phosphorus (TP) concentration, and filtered a second sample for determination of the concentration of chlorophyll *a* (Chl. A). Analyses of water samples for nutrients and chlorophyll was conducted by the analytical laboratory at the Southeast Environmental Research Center, Florida International University. Volunteers were trained to collect, handle, and store water samples properly to meet the quality-assurance/quality-control standards of the laboratory.

Content Keys

Research conducted by coral reef scientists at the Florida Fish and Wildlife Research Institute showed that there was a drastic decline prior to 1997 in the amount of live coral at the Content Keys, north of Big Pine Key. A special Florida Bay Watch station was established at this locality in August 1997 to provide water quality data in conjunction with ongoing biological monitoring of the reef. The protocol for this station followed that of the nearshore fixed stations (see above) with two exceptions. First, there were no data on rainfall during the previous 24 hours. Second, in addition to the seawater samples collected at the surface, additional samples were collected one meter above the bottom using a Wildco Water Bottle Kit. The water depth at this site (24°49.323 N, 83°29.335 W) was approximately 6 m.

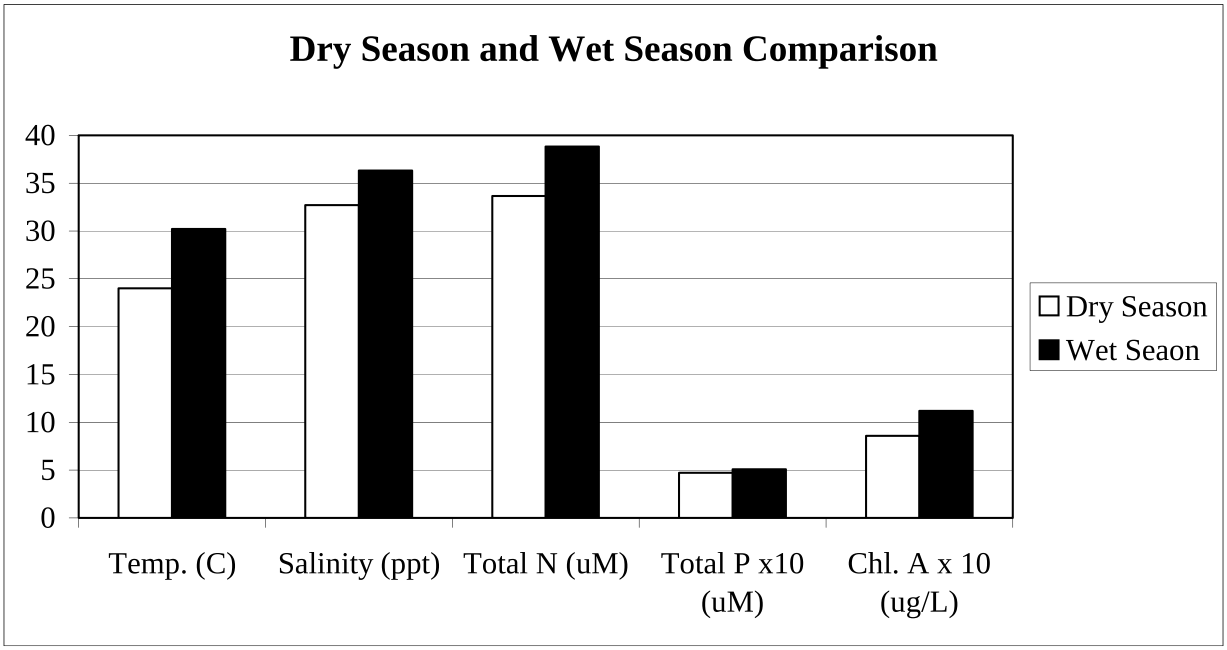
Key West Salt Ponds

Like all Keys waters, the Salt Ponds in Key West are naturally low in nutrients. This ecosystem, Key West's only remaining tidal wetland, is home to various species of plants, birds, and other animals. Increased nutrients from stormwater runoff or wastewater disrupt the system. Several sampling stations were established in the Salt Ponds in March 2001 to provide a year-long water quality data set. The protocol for these stations followed that of the nearshore fixed stations (see above).

Findings to Date

Nearshore Fixed Stations

A long-term analysis of data collected from all stations since the inception of the program was conducted. A total of 8,510 sampling events were conducted since 1994. Five parameters were analyzed: temperature, salinity, TN, TP, and Chl. A. Student's t-tests were performed to determine significant differences. A p value < 0.05 was defined as statistically significant. Because of high numbers of samples and low variances, many significant differences were detected. Figure 1 illustrates values for these parameters collected in the wet and dry season. All five parameters were significantly greater during the wet season (denoted by asterisks). Data from all bayside and oceanside stations are presented in Figure 2. Salinity was significantly greater for oceanside stations, while samples collected from the bayside were significantly greater for TN, TP, and Chl. A. There was no significant difference between oceanside and bayside temperatures. Figure 3 illustrates the differences between developed and natural shorelines. Developed shorelines were defined as canals and boat basins. Natural shorelines were undeveloped areas such as beaches and the ends of docks. Temperature, TN, and Chl. A levels were significantly higher in developed shorelines (canals/boast basins) compared to natural shorelines. A comparison between different geographic regions in the Keys is shown in Figure 4. Temperature values were similar for all three regions, as were salinity and TP. The upper Keys had the highest TN and Chl. A levels.

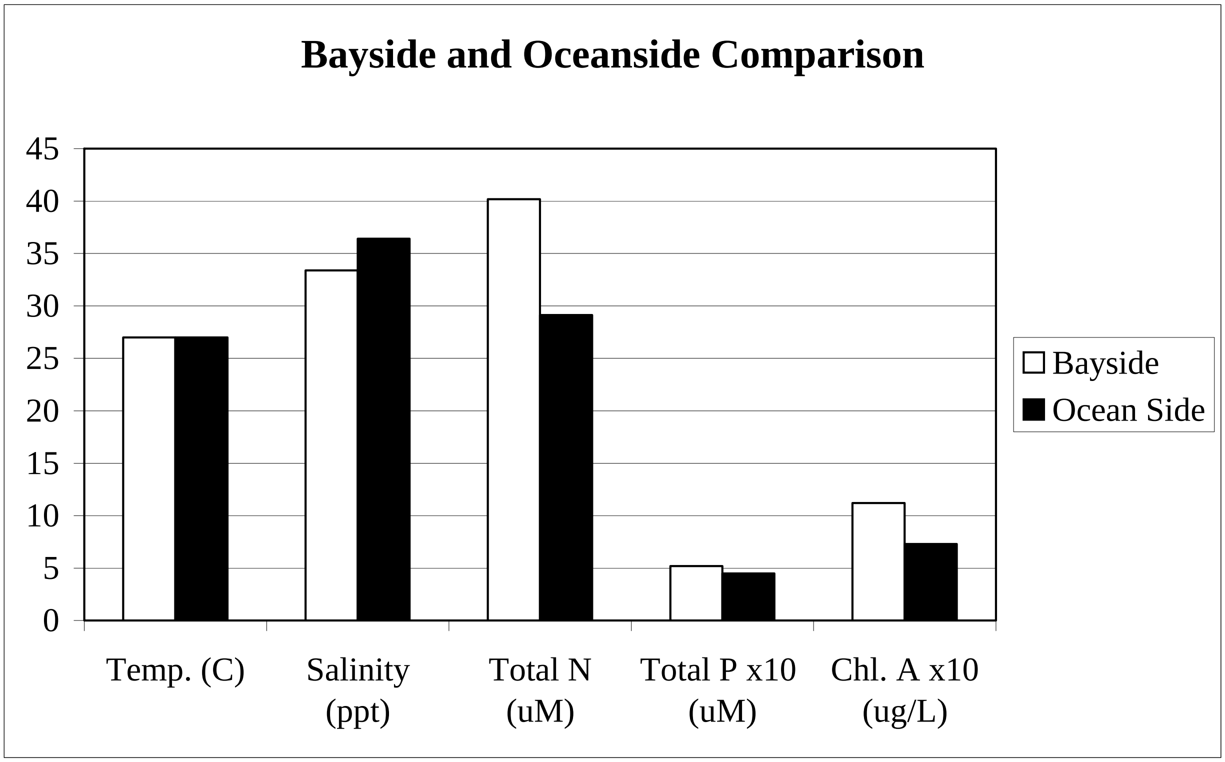


Dry Season					
	Temp	Salinity	Total N	Total P	Chl. A
Mean	24.0	32.7	33.64	0.47	0.86
Std. Error	0.1	0.1	0.24	0.01	0.02
Count	4290	4210	4247	4229	4112

Wet Season					
	Temp*	Salinity*	Total N*	Total P*	Chl. A*
Mean	30.2	36.3	38.82	0.51	1.12
Std. Error	0.0	0.1	0.33	0.01	0.15
Count	4061	3936	3971	3928	3775

Figure 1. Comparison of Dry Season and Wet Season water quality parameters.

The results of this study generally support a model of nearshore phosphorus loading of Florida Bay from various locations throughout the Keys, with an associated increase in the concentration of phytoplankton. Previously, when we compared nearshore Florida Bay Watch data for the five bayside, upper Keys stations sampled November 1996 – October 1997 at developed sites with data collected by FIU at five offshore stations in Florida Bay, we saw why. The concentration of Chl. A at developed, bayside shorelines in the upper Keys (0.86 μg/L) was more than twice the offshore concentration in Florida Bay (0.33 μg/L). Total phosphorus also was elevated at developed shorelines (0.49 μM), nearly three times the offshore value (0.17 μM). However, total nitrogen was virtually the same at developed shorelines (41.3 μM) and offshore (39.4 μM).



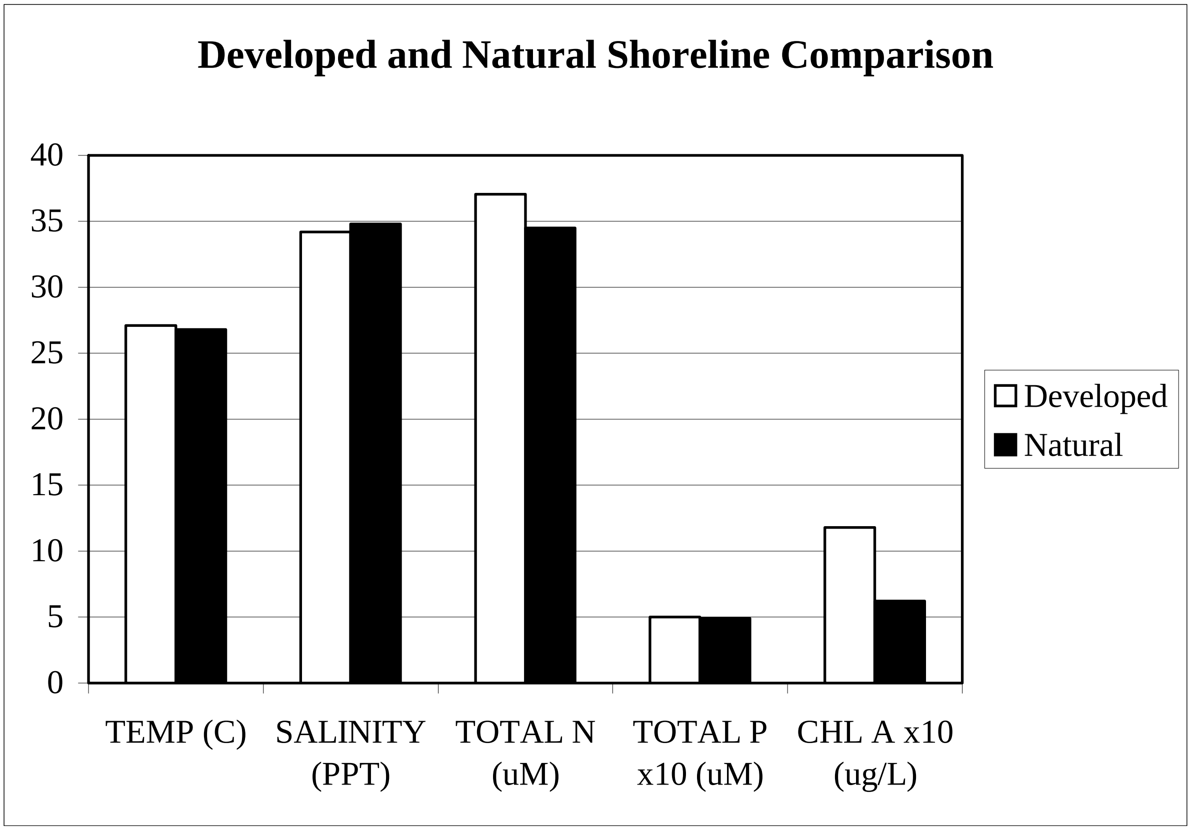
Bayside					
	Temp.	Salinity	Total N*	Total P*	Chl. A*
Mean	27.0	33.4	40.18	0.52	1.12
Std. Error	0.1	0.1	0.24	0.01	0.02
Count	5351	5186	5245	5204	5067

Oceanside					
	Temp.	Salinity*	Total N	Total P	Chl. A
Mean	27.0	36.4	29.12	0.45	0.73
Std. Error	4.2	0.1	0.31	0.01	0.20
Count	3042	2998	3016	3007	2873

Figure 2. Comparison of bayside and oceanside water quality parameters.

Content Keys

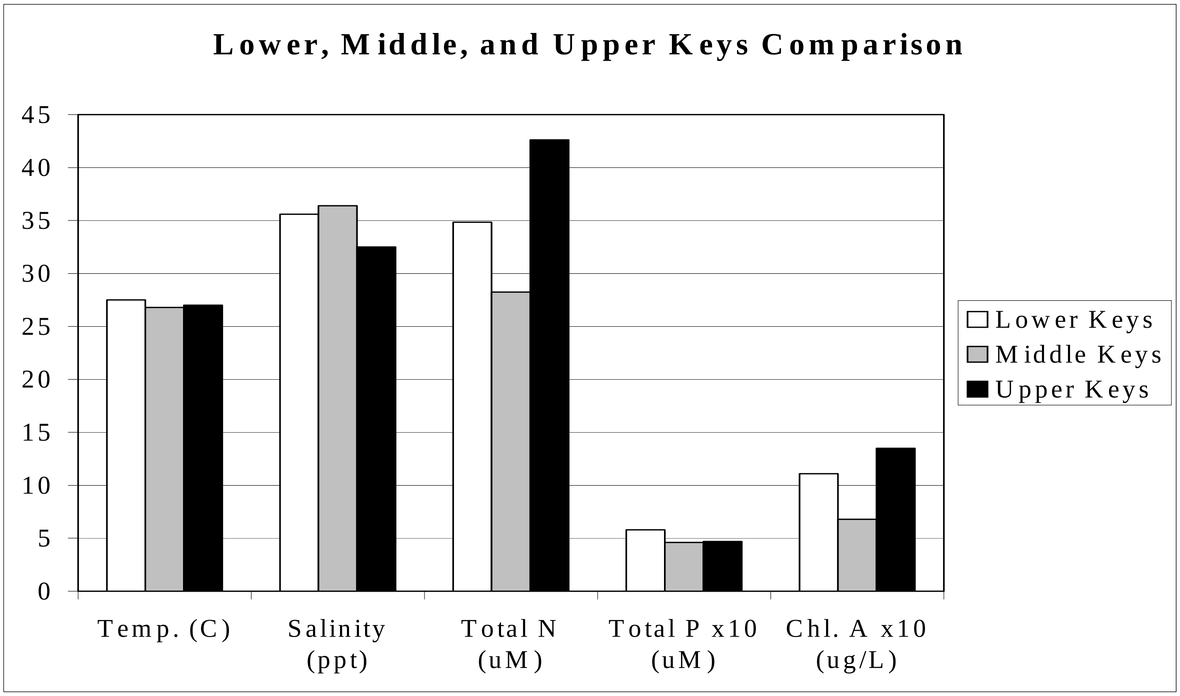
A graph comparing temperature, salinity, TN, TP, and Chl. A for samples collected at the surface and at depth is shown in Figure 5. These samples were collected between August 1997 and June 2000. Salinity was significantly higher for samples collected near the surface, while TN, TP and Chl. A levels were significantly higher for samples collected at depth. Since the mid-1990's, coral health in this area has declined. These higher nutrient and Chl. A levels at depth may have had a negative impact on coral health.



Developed					
	Temp.*	Salinity	Total N*	Total P	Chl. A*
Mean	27.1	34.3	37.05	0.50	1.18
Std. Error	0.1	0.1	0.26	0.01	0.11
Count	5356	5239	5300	5255	5063

Natural					
	Temp.	Salinity *	Total N	Total P	Chl. A
Mean	26.8	34.8	34.50	0.49	0.62
Std. Error	0.1	0.1	0.32	0.01	0.02
Count	2999	2908	2918	2905	2824

Figure 3. Comparison of developed and natural shoreline water quality parameters.

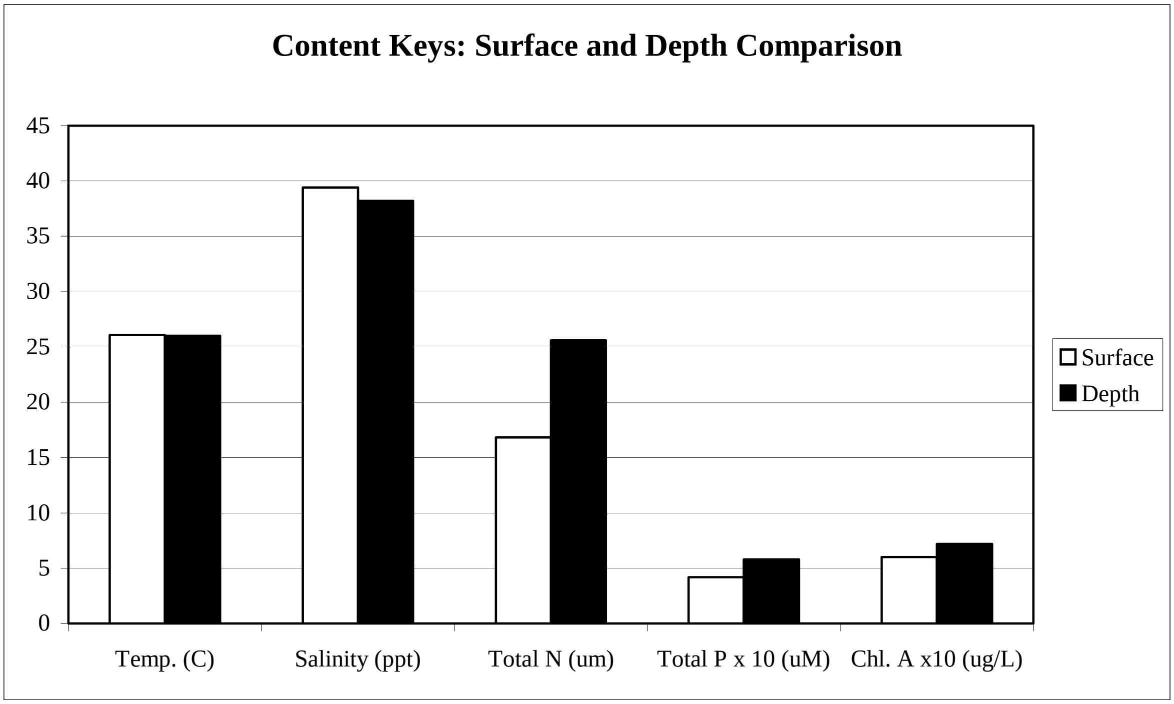


Lower Keys					
	Temp.	Salinity	Total N	Total P	Chl. A
Mean	27.5	35.6	34.83	0.58	1.11
Std. Error	0.1	0.1	0.39	0.02	0.05
Count	1794	1731	1772	1689	1734

Middle Keys					
	Temp.	Salinity	Total N	Total P	Chl. A
Mean	26.8	36.4	28.24	0.46	0.68
Std. Error	0.1	0.1	0.11	0.01	0.02
Count	2810	2767	2774	2778	2623

Upper Keys					
	Temp.	Salinity	Tot. N*	Total P	Chl. A*
Mean	27.0	32.5	42.61	0.47	1.35
Std. Error	0.1	0.1	0.29	0.01	0.16
Count	3794	3691	3712	3734	3601

Figure 4. Comparison of Lower, Middle, and Upper Keys water quality parameters.



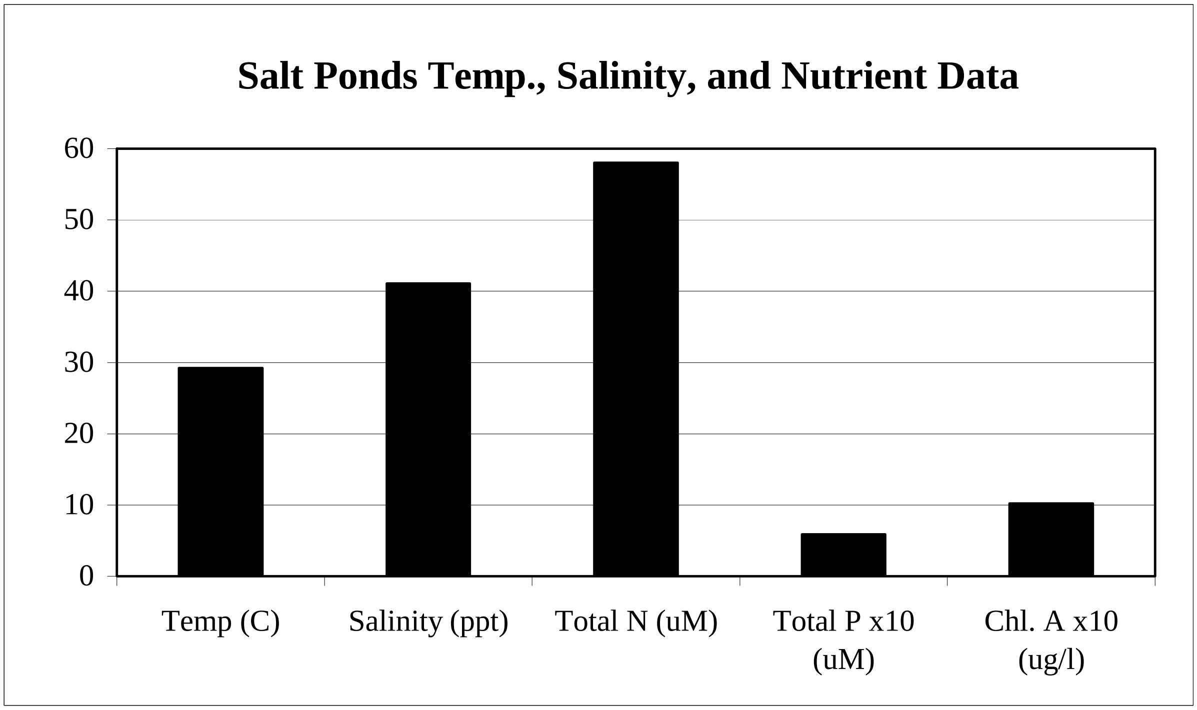
Surface					
	Temp.	Salinity *	Total N	Total P	Chl-a
Mean	26.1	39.4	16.82	0.42	0.60
Std. Error	0.3	0.3	0.66	0.02	0.04
Count	184	184	176	176	171

	Depth				
	Temp.	Salinity	Total N *	Total P*	Chl-a*
Mean	26.0	38.2	25.59	0.58	0.72
Std. Error	0.3	0.3	1.52	0.05	0.05
Count	177	174	169	169	164

Figure 5. Comparison of Content Keys surface and subsurface water quality parameters.

Key West Salt Ponds
Salt Ponds water quality was monitored from March 2001 through May 2002 (Fig. 6). Average temperature, salinity, and TN values were all higher in the Salt Ponds with respect to all lower

Keys nearshore fixed stations. With shallow depths and high rates of evaporation, the Salt Ponds are typically characterized by higher average temperature and higher salinity than nearshore waters. The average TN value in the Salt Ponds (58.0 µM) was higher than any fixed nearshore station average in the Florida Bay Watch database. The source of these increased nutrients may be from stormwater runoff retention, wastewater, or natural inputs such as bird droppings.



	TEMP	SALINITY	TOTAL N	TOTAL P	CHL A
Mean	29.2	41.1	58.04	0.59	1.02
Std. Error	0.6	2.2	5.20	0.06	0.19
Count	77	77	60	59	58

Figure 6. Salt Ponds water quality parameters.

Florida Keys Watch

Brad Rosov, The Nature Conservancy, Sugarloaf Key, FL.

Goals

Florida Keys Watch (FKW) was a canal water quality monitoring program designed to assess levels of bacterial and human-borne viral contamination in a series of canals throughout the Florida Keys. The mission of this program was to document the status of canal water quality and to determine whether human waste was a source of contamination.

Good water quality is essential for maintaining healthy aquatic habitats such as seagrass beds, mangroves, and coral reefs. Potential threats to the condition of nearshore waters stem from natural and anthropogenic processes. Nutrients from poorly treated wastewater and stormwater runoff are potential sources of pollution in the nearshore waters in the Florida Keys. Without a centralized sewage treatment system, the Keys rely upon more than 23,000 private onsite systems and approximately 246 small wastewater treatment plants to manage their wastewater load. The onsite systems are composed of approximately 15,200 permitted septic systems, 640 Advanced Treatment Units, and 7,200 unknown systems (2,800 of which are believed to be illegal cess pits). These systems send water that is poorly treated or untreated into the porous limestone foundation just below a thin veneer of soil. Tides and heavy rains flush out this tainted groundwater and transport nutrient, bacterial, viral, and other contaminants from the groundwater into adjacent canal systems and nearshore waters. This contamination poses a potential human health risk as well as a threat to the health of the aquatic ecosystem.

FKW was a partnership established between the U.S. Environmental Protection Agency (EPA) and The Nature Conservancy (TNC), a private, non-profit conservation organization. The EPA provided funding for the analysis of viral samples. TNC provided funding and acted as the managing partner by providing staff support and coordination for the program.

This report presents data collected from the inception of the program in August 2002 through January 2003. Although viral samples were collected during this period, the results have not been determined at the time of writing this report.

Methodology

FKW was modeled from a previous canal water quality study conducted by University of South Florida (USF) researchers in 1999. In the earlier study, water samples were collected from 19 canal sites and analyzed for a suite of bacterial and viral indicators that can potentially cause disease in humans. Ten of the sampling stations in the USF study were included in FKW. Seven additional sites were identified through use of the Monroe County Sanitary Wastewater Master Plan and are recognized as “hotspots” (areas that will receive a community wastewater collection and treatment system by the year 2010). In all, FKW incorporated a total of 17 canal sampling stations at both public and private sites (Table 1). Stations were distributed between Mile Marker 105 in Key Largo and Mile Marker 10 in Boca Chica (Table 1) and included sites both bayside and oceanside. One station (#14) was changed after several sampling events and only the data from the newer station were included in this report.

Data were collected from each station by TNC staff or volunteers. Each collector was trained in sampling techniques including filling out data forms, calibrating field equipment, and handling water samples to ensure the integrity of the data. The TNC Marine Conservation Program Manager supervised a trained intern who periodically evaluated volunteers on the care and manner with which they sampled, and all data went through a quality control check to identify possible errors. All protocols and methods utilized for this projected were included in a Quality Assurance Project Plan (QAPP) submitted to and approved by the Region IV Water Management Division of the EPA. A database was maintained to track the schedule of volunteer training, as described in the QAPP.

Every two weeks, a team of two volunteers and the marine intern collected data and water samples from all 17 stations. The following information was recorded on a standardized data form: station identification number, date, time, tide, salinity, dissolved oxygen (from surface and at depth), temperature (from surface and at depth), and rainfall in the past 24 hours. Rainfall data were scored as a “0,” “1,” or “2.” A score of “0” denoted that there was no rainfall over the previous 24 hours, “1” denoted that 0.1-0.5 inches of rain was recorded over the previous 24 hours, and “2” denoted that over 0.5 inches of rainfall was recorded over the previous 24 hours. In addition, two 100-ml water samples were collected from each station to determine levels of enterococcus bacterial contamination. Enterococcus bacteria are commonly found in association with warm-blooded animals, including raccoons, dogs, and humans.

All water samples and data sheets were collected from volunteers following each sampling and were brought to TNC’s office in Sugarloaf Key. Analysis of these water samples was conducted at the TNC office through use of the Enterolert most probable number (MPN) technique. TNC staff were trained to analyze samples properly and meet the quality assurance/quality control standards as described in the QAPP. All data from the field forms and sample analysis were then checked for errors and entered into a database managed by TNC.

Following four months of data collection (mid-January 2003), samples were collected from six of the canals with the highest levels of bacterial contamination. These samples were sent to Biological Consulting Services, Inc. (BCS) for laboratory analysis for the presence of viral contamination associated with humans. Although not available for this report, the results from this portion of the project will determine if human sewage is a source for viral contamination in these canals.

Sampling also occurred following episodic events, such as a heavy rainfall. It is theorized that heavy rainfalls promote higher rates of flushing of groundwater into canal waters. Due to logistical reasons, only 6-8 stations were sampled following episodic events. A total of five viral samples were collected following an episodic event through the course of this study.

Results

Between 8 August 2002 and 28 January 2003, water quality sampling took place every two weeks for a total of 13 times at the FKW canal stations. Due to logistical reasons, data could not be obtained from several stations during these sampling dates. Additionally, four episodic sampling events occurred at six lower Keys stations.

Enterococcus

Enterococcus is a common class of bacteria that thrives in the guts of warm-blooded animals. This suite of bacteria is considered to be the best indicator of bacterial contamination because it has the ability to survive longer in warm marine waters. In 1986, the EPA set the guideline with the maximum density of 104 Colony Forming Units (CFU) of enterococcus per 100 ml of marine water to be considered safe for swimming. The state-sponsored Florida Healthy Beaches program utilizes the following standards when evaluating the condition of swimming beaches:

- 0-34 CFU/100 ml - acceptable
- 35-103 CFU/100 ml - moderate
- 104 CFU and above - poor

Enterococcus bacteria levels in canal water samples were calculated for each station (Table 2). Because it became evident that rainfall significantly affected enterococcus levels, the data were broken down into four categories: “Total Samples from Station,” “No Rain Samples,” “Total Rain Samples,” and “Heavy Rain Samples Only” (Table 2). “Total Samples from Station” refers to the average MPN of enterococcus for all samples collected at the station. “No Rain Samples” refers to the average MPN for all samples that received a rainfall score of “0”. “Total Rain Samples” refers to the average MPN for all samples that received a rainfall score of “1” and “2.” “Heavy Rain Samples Only” refers to the average MPN of enterococcus for all samples that received a rainfall score of “2.” It should be noted that a very heavy rainfall occurred on 12/8/02 and the subsequent enterococcus data collected was extremely high for many of the stations (CFU’s were recorded in the thousands). Despite this, the results of this anomaly have been incorporated into the following analysis. No stations exceeded the EPA’s recommended enterococcus maximum (104 CFU/100 ml) for samples collected following “no rainfall,” while 59% of these stations exceeded the limit following a rainfall (see bottom of Table 2). Graph 1 illustrates the percentage of samples that exceeded the recommended enterococcus maximum. A similar trend was shown - only 7% of samples following no rain exceeded the limit, while 44% of the samples following a heavy rain exceeded the limit.

Using Florida Healthy Beaches standards, four stations were deemed acceptable, six stations were moderate, and seven stations were poor when analyzing “Total Samples Taken from Station.” Analysis of “No Rain Samples” revealed that 12 stations were deemed acceptable, five stations were moderate, and no station was poor. “Heavy Rain Samples” revealed that only three stations were deemed acceptable, four stations were moderate, and 10 stations were poor. There was high variability for enterococcus density within individual stations as reflected in high standard errors (not presented in this report).

Dissolved Oxygen, Temperature, and Salinity

Most fish, crustaceans, and other marine organisms require oxygen. When dissolved oxygen falls below certain levels, these organisms become stressed or die. When waters are enriched with high levels of nutrients, benthic algae and phytoplankton may grow at high rates. As these organisms die, bacteria take up oxygen as they decompose organic matter. Canal systems with contaminants such as high nutrient, bacterial, or viral levels often demonstrate diminished dissolved oxygen levels that stress aquatic organisms. Florida State Statute 62-302.530 states that dissolved oxygen levels in marine waters “shall never be less than 4.0 mg/l.”

Table 3 illustrates the average canal dissolved oxygen levels recorded from the surface and at depth in each canal station. All readings were conducted with a YSI Dissolved Oxygen meter in the early to late morning (7:30 AM-12:00 PM). Dissolved oxygen levels are often lower near the bottom, where most of the decomposition occurs. After averaging the two values from each site, it was determined that the average of four stations fell below the acceptable limit of 4.0 mg/l. The lowest value was 2.18 mg/l (station #17); the highest was 5.91 mg/l (station #11). The average dissolved oxygen level in the series of canals was determined to be 3.52 mg/l, which fell below the acceptable limit. The standard error within and between stations was low.

Table 1 (see text for explanation)

Florida Keys Watch Stations	**Site #**	**Mile Marker**	**Public/Private**
Boca Chica, Boca Chica Ocean Shores	1	10	Public
Big Coppitt, Porpoise Point	2	10	Private
Saddlebunch Keys, Bay Point	3	15	Public
Sugarloaf Key, Sugarloaf Shores	4	17	Private
Cudjoe Key, Cudjoe Gardens	5	21	Public
Cudjoe Key, Cutthroat Estates	6	22	Private
Big Pine Key, Eden Pines	7	30	Private
Big Pine Key, Whispering Pines	8	31	Public
Marathon, 27th Ave	9	48.5	Private
Marathon, Dolphin Dr.	10	51	Public
Duck Key	11	61	Private
Conch Key	12	63	Public
Islamorada, Port Antigua	13	74.5	Private
Tavernier, Banyan Lane	14	92	Private
Key Largo, Rock Harbour	15	98.5	Private
Key Largo, Pimlico Lane	16	103	Private
Key Largo, Sexton Cove Estates	17	105.5	Private

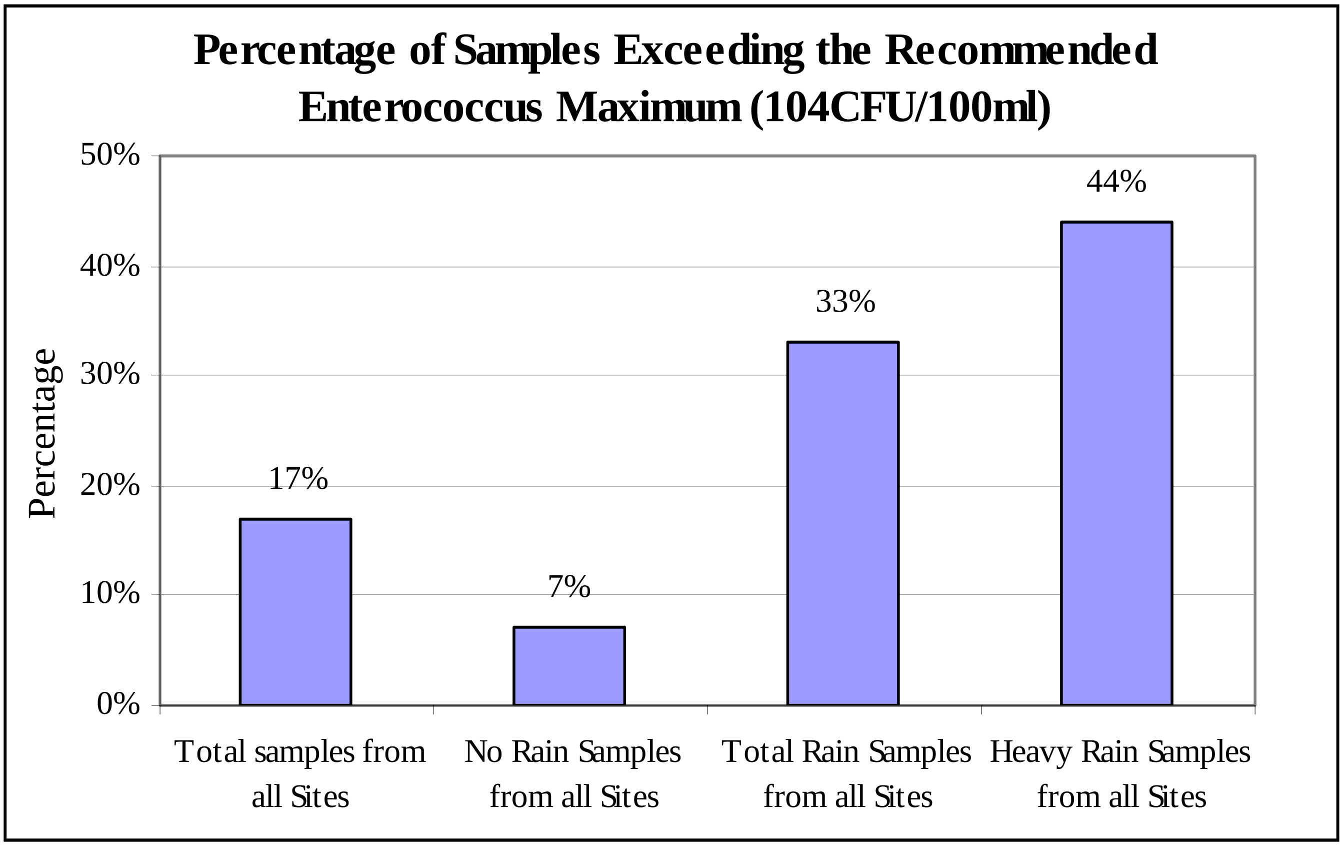
Table 2 (see text for explanation)

Enterococcus Averages (CFU/100 ml)

Station Identification	Total Samples from Station	No Rain Samples	Total Rain Samples	Heavy Rain Samples Only
#1, Boca Chica, Ocean Shores	**687.9**	9.4	**1477.3**	**3585.4**
#2, Big Coppitt, Porpoise Point	**447.7**	22.0	**944.3**	**2759.0**
#3, Saddlebunch Keys, Bay Point	**753.4**	65.3	**1441.4**	**2826.1**
#4, Sugarloaf Key, Sugarloaf Shores	**262.1**	10.7	**513.5**	**1154.7**
#5, Cudjoe Key, Cudjoe Gardens	59.1	13.0	99.4	**133.0**
#6, Cudjoe Key, Cutthroat Estates	**231.7**	15.1	**447.6**	**865.3**
#7, Big Pine Key, Eden Pines	**151.8**	6.3	**297.4**	**378.0**
#8, Big Pine Key, Whispering Pines	61.9	48.4	89.7	45.1
#9, Marathon, 27th Ave	7.4	5.6	13.5	10.0
#10, Marathon, Dolphin Dr.	61.8	21.6	**152.4**	52.0
#11, Duck Key	5.8	5.6	6.7	10.0
#12, Conch Key	58.9	65.1	36.3	52.0
#13, Islamorada, Port Antigua	5.8	2.8	12.6	30.5
#14, Tavernier, Banyan Lane	98.5	38.7	**189.5**	**412.0**
#15, Key Largo, Rock Harbour	26.7	26.8	26.4	85.5
#16, Key Largo, Pimlico Lane	77.2	40.1	**170.1**	**335.0**
#17, Key Largo, Sexton Cove Estates	**228.0**	11.7	**876.8**	**2459.5**
Ave. enterococcus levels for all stations	**189.7**	24.0	**399.7**	**893.7**
% Stations exceeding 104 CFU/100 ml	41%	0%	59%	59%

Note: bold values represent enterococcus averages that exceeded 104 CFU/100 ml.

Graph 1 ***(see text for explanation)***



	Total samples from all Sites	No Rain Samples from all Sites	Total Rain Samples from all Sites	Heavy Rain Samples from all Sites
Number of Samples	231	144	89	36
# of Samples Exceeding 104 CFU	39	10	29	16
% of Samples Exceeding 104 CFU	17%	7%	33%	44%

Table 3 (see text for explanation)

Dissolved Oxygen, Temperature, and Salinity Averages

Station Identification	Dissolved Oxygen (mg/l)	Temperature (C)	Salinity (ppt)
#1, Boca Chica, Ocean Shores	4.77	27.2	36.2
#2, Big Coppitt, Porpoise Point	5.34	26.2	36.2
#3, Saddlebunch Keys, Bay Point	4.38	26.0	36.9
#4, Sugarloaf Key, Sugarloaf Shores	5.55	26.1	36.2
#5, Cudjoe Key, Cudjoe Gardens	5.08	26.3	36.2
#6, Cudjoe Key, Cutthroat Estates	**3.64**	26.6	35.6
#7, Big Pine Key, Eden Pines	4.13	26.8	32.8
#8, Big Pine Key, Whispering Pines	**2.25**	26.1	34.9
#9, Marathon, 27th Ave	4.59	26.7	36.6
#10, Marathon, Dolphin Dr.	4.22	26.4	37.2
#11, Duck Key	5.91	26.0	37.1
#12, Conch Key	5.21	25.7	36.6
#13, Islamorada, Port Antigua	5.23	27.1	36.8
#14, Tavernier, Banyan Lane	4.31	23.4	35.5
#15, Key Largo, Rock Harbour	4.37	26.3	29.2
#16, Key Largo, Pimlico Lane	**3.39**	26.5	26.2
#17, Key Largo, Sexton Cove Estates	**2.18**	26.9	28.2
Ave. DO, Temp, and Salinity	4.39	26.3	34.6

Note: bold values represent dissolved oxygen averages that were below the 4.0 mg/l standard.

Seagrass Monitoring in the Florida Keys National Marine Sanctuary

James W. Fourqurean (Southeast Environmental Research Center and Department of Biology, Florida International University, Miami, FL)
Michael J. Durako (Center for Marine Science and Department of Biology, University of North Carolina at Wilmington, Wilmington, NC)
Joseph C. Zieman (Department of Environmental Science, University of Virginia, Charlottesville, VA)
Susie P. Escorcia and Leanne M. Rutten (Southeast Environmental Research Center and Department of Biology, Florida International University, Miami, FL)

Goals

The general objective of seagrass monitoring in the Florida Keys National Marine Sanctuary (FKNMS) (part of the Water Quality Protection Program) is to measure the status and trends of seagrass communities to evaluate progress toward protecting and restoring the living marine resources of the Sanctuary. The scope and depth of this monitoring effort are without precedent or peer for seagrass ecosystems throughout the world. Specific objectives are: 1) To provide data needed to make unbiased, statistically rigorous statements about the status and temporal trends of seagrass communities in the Sanctuary as a whole and within defined strata; 2) To help define reference conditions in order to develop resource-based water quality standards; and 3) To provide a framework for testing hypothesized pollutant fate/effect relationships through process-oriented research and monitoring. In order to meet these objectives, we have developed these goals for the project:

- Define the present distribution of seagrasses within the FKNMS
- Provide high-quality, quantitative data on the status of the seagrasses within the FKNMS
- Quantify the importance of seagrass primary production in the FKNMS
- Define the baseline conditions for the seagrass communities
- Determine relationships between water quality and seagrass status
- Detect trends in the distribution and status of the seagrass communities

Methods

To reach these goals, four kinds of data are being collected in seagrass beds in the FKNMS:

- Distribution and abundance of seagrasses using rapid assessment Braun-Blanquet surveys
- Demographics of the seagrass communities using leaf-scar counting and population demographics techniques
- Seagrass productivity of the dominant species of seagrass in the FKNMS (*Thalassia testudinum*) using the leaf-mark and harvest method
- Seagrass nutrient availability using tissue concentration assays

These data are being collected at three different types of sites within the FKNMS:

Level 1 Stations: Sampled quarterly for seagrass abundance, demographics, productivity, and nutrient availability. These stations are all co-located with Water Quality Monitoring Project stations (Fig. 1).

Level 2 Stations: Randomly selected locations within the FKNMS, sampled annually for seagrass abundance, demographics, and nutrient availability. Each year, new locations for Level 2 stations are chosen.

Level 3 Stations: Randomly selected locations within the FKNMS, sampled annually for seagrass abundance. Each year, new locations for Level 3 stations are chosen.

We are assessing both interannual and seasonal trends in seagrass communities. The mix of site types is intended to monitor trends through quarterly sampling at a few permanent locations (Level 1 sites) and to annually characterize the broader seagrass population through less intensive, one-time sampling at more locations (Level 2 and 3 sites).

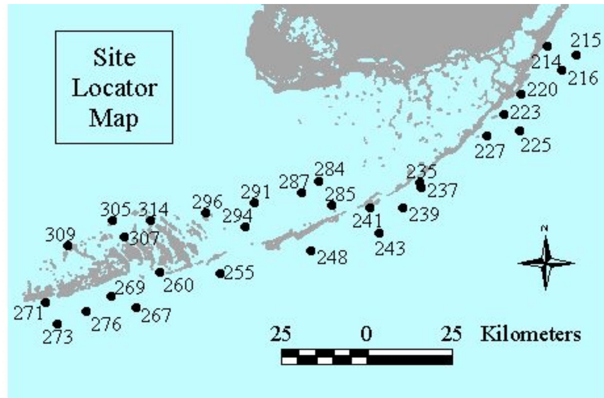


Figure 1. Map of the Florida Keys showing the location of Level 1 seagrass status and trends monitoring sites. Site numbers correspond to stations of the Water Quality Monitoring

Findings to Date

The significant changes in seagrass communities at the permanent Level 1 stations that we reported last fiscal year continue to be present after an additional year of sampling. These changes are consistent with model predictions of nutrient-induced changes of these systems. There may be reasons for these observations that are unrelated to human activities in the region, but the spatial pattern of changes and the agreement of the changes with models of the system suggest that there is regional-scale change in nutrient availability that is causing changes in seagrass beds over a wide portion of the FKNMS.

In 2003, we resurveyed 202 Level 2 and Level 3 stations that were last visited during the summer of 1996. The data collected during this resurvey are still being assessed, but preliminary analyses indicate that there are no large-spatial-scale trends in the abundance of the dominant benthic plant types over these seven years.

In general, nutrient addition to aquatic environments shifts the competitive balance to faster-growing primary producers. The consequence of this generality in seagrass-dominated environments is that seagrasses are the dominant primary producers in oligotrophic conditions. As nutrient availability increases, there is an increase in the importance of macroalgae, both free-living and epiphytic, with a concomitant decrease in seagrasses because of competition for light. Macroalgae lose out to even faster-growing microalgae as nutrient availability continues to increase. First, epiphytic microalgae replace epiphytic macroalgae on seagrasses; then planktonic microalgae bloom and deprive all benthic plants of light under the most eutrophic conditions. The South Florida case is more complicated than the general case described above because there are six common seagrass species in South Florida. These species have different nutrient and light requirements, and have differing responses to eutrophication. Large expanses of the shallow marine environments in South Florida are so oligotrophic that biomass and growth of even the slowest-growing local seagrass species, *Thalassia testudinum*, are nutrient-limited; at this very oligotrophic end of the spectrum, increases in nutrient availability actually cause increases in seagrass biomass and growth rate. As nutrient availability increases beyond what is required by a dense stand of *T. testudinum*, there are other seagrass species that will out-compete it (Fig. 2). The relative importance of the various primary producers, then, can be used to assess the trophic state of the community.

Each species in the species dominance-eutrophication gradient model (Fig. 2) can potentially dominate over a range of nutrient availability and the model predicts a change in species dominance as nutrient availability changes. These changes are not instantaneous, however. Field evidence suggests that species replacements may take place on a time scale of a decade or more. It is desirable that we be able to predict the tendency of the system to undergo these changes in species dominance before they occur, so that management actions can be taken. Tissue nutrient concentrations can be monitored to assess the relative availability of nutrients to the plants. For phytoplankton communities, this idea is captured in the interpretation of elemental ratios compared to the familiar "Redfield ratio" of 106C:16N:1P. For the seagrass *T. testudinum*, the critical ratio of N:P in green leaves that indicates a balance in the availability of N and P is Figure 2. Conceptual model showing the change in importance of primary producers as nutrient availability increases from low (oligotrophic) to high (eutrophic).approximately 30:1, and monitoring deviations from this ratio can be used to infer whether N or P availabilities are limiting this species' growth. Hence, *T. testudinum* is likely to be replaced by faster-growing competitors if nutrient availability is such that the N:P of its leaves is ca. 30:1. A change in the N:P in time to a value closer to 30:1 is indicative of eutrophication (Fig. 3).

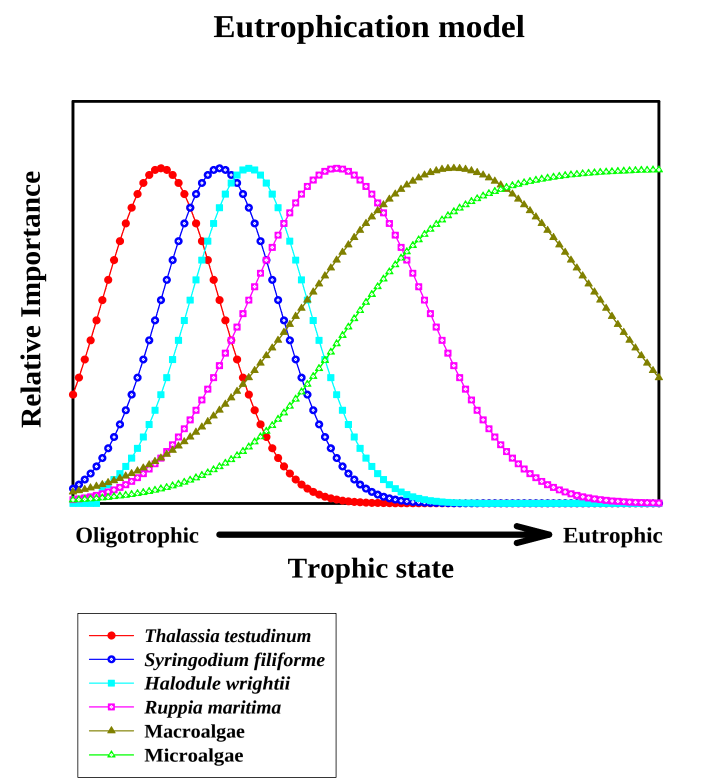


Figure 2. Conceptual model showing the change in importance of primary producers as nutrient availability increases from low (oligotrophic) to high (eutrophic).

These models lead directly to a definition of trends likely to be encountered in the seagrass communities of South Florida if humans are causing regional changes in nutrient availability because of alterations to quantity and quality of freshwater inputs to the marine ecosystem:

1) regional eutrophication will cause N:P ratios of seagrasses to approach 30:1 from higher or lower values indicative of oligotrophic conditions; and

2) regional eutrophication will cause a shift in species dominance in South Florida seagrass beds.

The first responses to eutrophication will be evidenced by an increase in the relative abundance of fast-growing seagrass species (*H. wrightii* and *S. filiforme*) at the expense of the now dominant, slow-growing *T. testudinum*. At later stages of eutrophication, macroalgae and microalgae will become the dominant primary producers.

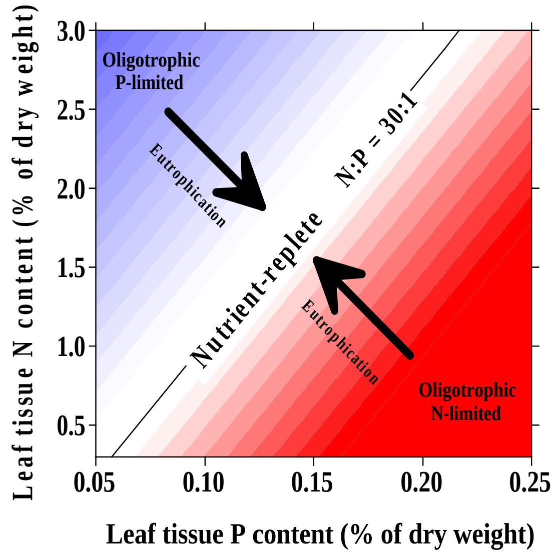


Figure 3. Conceptual model indicating how elemental ratios of seagrasses responds to increasing nutrient availability.

At four nearshore Level 1 sites in the Florida Keys, there has been an increase in the relative abundance of macroalgae over the period 1995-2003 that is consistent with an increase in nutrient availability. At none of these sites has there yet been a decrease in seagrass abundance, but our conceptual model predicts that increases in fast-growing macroalgae should precede decreases in seagrass abundance (Fig. 2). One example, from site 235 offshore of Lower Matecumbe Key, shows how macroalgae have steadily increased in abundance over the monitoring period (Fig. 4). In addition to these sites where relative abundance of primary producers has changed, at four more Level 1 sites there have been long-term shifts in the ratio of nitrogen to phosphorus in seagrass leaves that are consistent with increases in nutrient availability (Fig. 5).

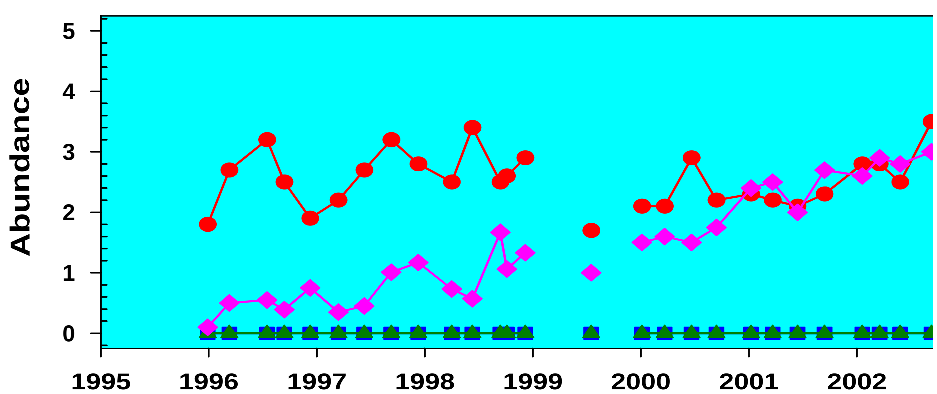


Figure 4. At Level 1 station 235 (see Fig. 1 for location) there has been a slow and consistent shift in species abundance, with faster-growing macroalgae becoming more abundant over the seven-year period. This change is consistent with model predictions

The sites that showed changes consistent with increased nutrient availability were not randomly distributed across the Sanctuary. All of these sites were relatively close to shore in the Middle and Lower Keys (Fig. 6). The lack of any such changes in the Upper Keys suggests that the factor driving the observed changes is not present across the entire Sanctuary, so factors acting at the global scale (like global warming or coastal overfishing) are not likely responsible for the observations. In addition to Level 1 sites that are exhibiting changes that are consistent with long-term increase in nutrient supply, two additional sites were severely impacted by hurricanes over the course of the monitoring period.

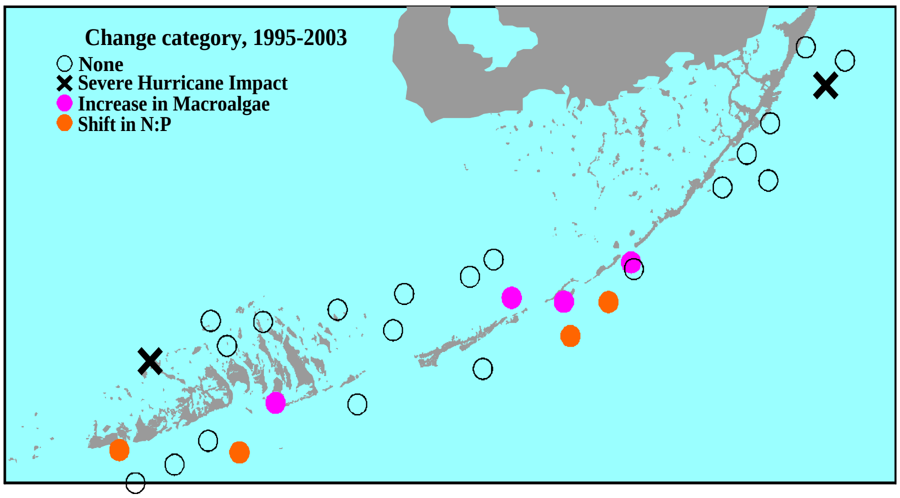


Figure 6. Long-term changes in seagrass beds at Level 1 sites.

Resurveying the Level 2 and Level 3 sites revealed no spatially consistent patterns in changes in relative abundance of seagrass communities throughout the Sanctuary. The mean changes in Braun-Blanquet density for the major taxa for the period 1996 and 2003 were not significantly different from zero (Fig. 7), but there were some locations that had large differences between 1996 and 2003. Whether these changes were real changes in the benthic communities or artifacts caused by small scale spatial heterogeneity is currently being investigated. There were some areas, such as around Islamorada, that showed declines in *Thalassia* in a large area contiguous with Level 1 permanent sites that exhibited changes consistent with eutrophication (see Fig. 8 for spatial pattern of change and Fig. 6 for Level 1 site summary). However, other regions of apparent change were not consistent with the patterns seen at the permanent sites. In FY 2004, we will resample an additional 200 sites that were surveyed in 1997.

Our surveys have provided clear documentation of the distribution and importance of seagrasses in the FKNMS. The seagrass bed that carpets 80% of the FKNMS is part of the largest documented contiguous seagrass bed on earth. These extensive meadows are vital for the ecological health of the FKNMS and the marine ecosystems of all of South Florida. Maps of spatial distributions can be found at (http://www.fiu.edu/~seagrass/) or DVD.

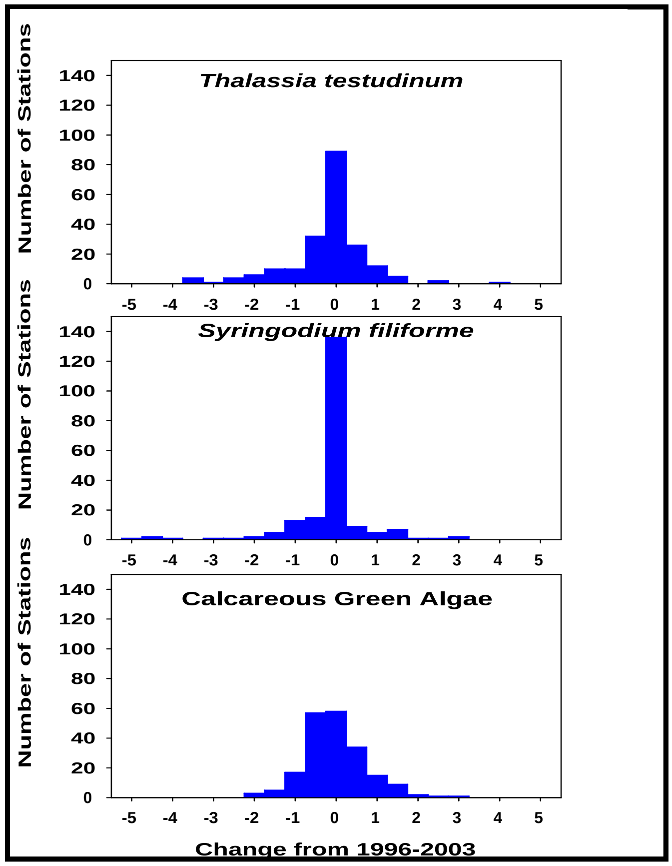


Figure 7. Frequency distributions of changes in Braun-Blanquet densities for the three most common taxa based on revisiting 202 sites in 2003 that were originally surveyed in 1996. The mean change in density for all three taxa is not significantly different from zero.

Our permanent monitoring sites have provided valuable data on the interannual and seasonal variability of seagrass cover and abundance. Time series of species composition, seagrass productivity, nutrient availability, and physical parameters can be found for each permanent monitoring site on the web site or the DVD. There have been some striking trends in the seagrass communities at these permanent sites: seagrasses were lost completely at 3 of the 30 sites during hurricanes over the last four years. At the remaining 27 sites, the benthic communities are relatively stable. There are no common trends across the sites in seagrass cover or community composition.

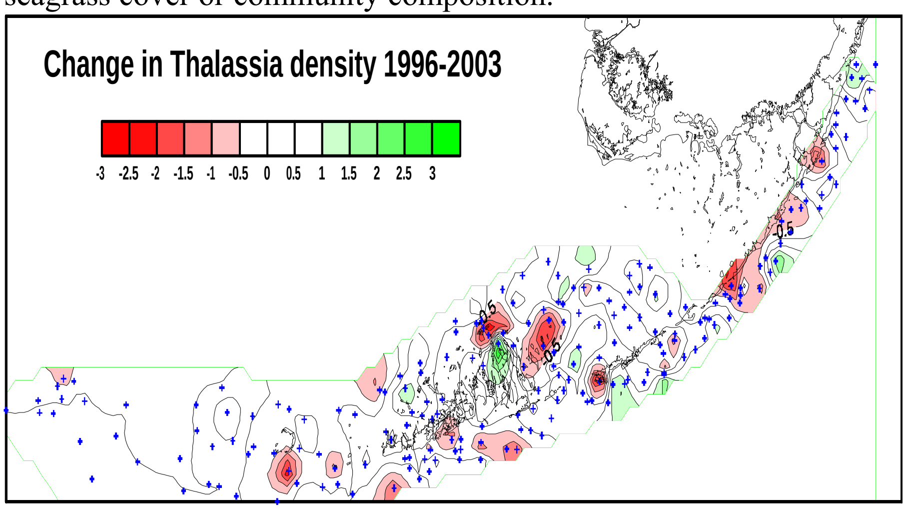


Figure 8. Spatial pattern in the changes in the Braun-Blanquet density of *Thalassia testudinum* at Level 2 and 3 sites surveyed in 1996 and revisited in 2003.

This can be interpreted to mean that there are no regional trends in the health of the seagrass beds represented by the permanent monitoring sites that can be detected with the six years of monitoring data. However, manipulative experiments in seagrass beds in south Florida demonstrate that the time course of the response of seagrass beds to eutrophication is on the order of decades, and we do not understand completely the interaction humans have with the natural dynamics of these systems. These 30 sites should continue to be monitored on a quarterly basis.

Detailed analyses of the monitoring data have led to 17 peer-reviewed publications in the peer-reviewed scientific literature. These publications address aspects of the functioning, status and trends of benthic communities as well as lay the groundwork for forecasting future anthropogenic impacts on this ecosystem.

Acknowledgments

This data report represents the dedicated work of many people. Craig Rose, Alan Willsie, Brad Peterson, and Leanne Rutten led the field collection efforts and spearheaded the compilation of the data report; Meredith Ferdie, Dottie Byron, Virginia Cornett, Sean Meehan, and Kevin Cunniff collectively put in the thousands of hours in the field and laboratory that went into the collection of these data. The fieldwork was conducted under permits FKNMS-2003-036 from the FKNMS, FDEP permit number 1587, FDEP Parks and Recreation Permit number 5-04-09, and permit number DRTO-2003-SCI-0009 from the National Park Service.

Publications Resulting from the Project to Date (Chronological Order)

Rose, C.D., W.C. Sharp, W.J. Kenworthy, J.H. Hunt, W.G. Lyons, E.J. Prager, J.F. Valentine, M.O. Hall, P. Whitfield, and J.W. Fourqurean. 1999. Sea urchin overgrazing of a large seagrass bed in outer Florida Bay. *Marine Ecology Progress Series* 190: 211-222.

Fourqurean, J.W., A. Willsie, C.D. Rose, and L.M. Rutten. 2001. Spatial and temporal pattern in seagrass community composition and productivity in south Florida. *Marine Biology* 138: 341-354.

Davis, B.C., and J.W. Fourqurean. 2001. Determining species interactions between the tropical alga, *Halimeda incrassata*, and the seagrass, *Thalassia testudinum*. *Aquatic Botany* 71(3): 217-232.

Peterson, B.J., and J.W. Fourqurean. 2001. Spatial variability of *Thalassia testudinum* population demographics in south Florida. *Limnology and Oceanography* 46(5): 1077-1090.

Fourqurean, J.W., M.J. Durako, M.O. Hall, and L.N. Hefty. 2002. Seagrass distribution in south Florida: a multi-agency coordinated monitoring program. Pp. 497-522 in: Porter, J.W. and K.G. Porter, eds. The Everglades, Florida Bay, and the coral reefs of the Florida Keys. CRC Press LLC, Boca Raton, FL. 1000 pp.

Peterson, B.J., C.D. Rose, L.M. Rutten, and J.W. Fourqurean. 2002. Disturbance and recovery following catastrophic grazing: studies of a successional chronosequence in a seagrass bed. *Oikos* 97: 361-370.

Fourqurean, J.W., and J.C. Zieman. 2002. Seagrass nutrient content reveals regional patterns of relative availability of nitrogen and phosphorus in the Florida Keys, FL, USA. *Biogeochemistry* 61: 229-245.

Fourqurean, J.W., and L.M. Rutten. 2003. Monitoring of soft-bottom marine habitat on the regional scale: the competing goals of spatial and temporal resolution. Pp. 257-288 in: Busch, D. and J.C. Trexler, eds. Ecological monitoring of ecosystem initiatives. Island Press, Washington, D.C.

Fourqurean, J.W., J.N. Boyer, M.J. Durako, L.N. Hefty, and B.J. Peterson. 2003. The response of seagrass distribution to changing water quality: predictive models from monitoring data. *Ecological Applications* 13(2): 474-489.

Anderson, W.T. and J.W. Fourqurean. 2003. Intra- and interannual variability in seagrass carbon and nitrogen stable isotopes from south Florida, a preliminary study. *Organic Geochemistry* 34: 185-194.

Fourqurean, J.W., S.P. Escorcia, W.T. Anderson, and J.C. Zieman. Spatial and seasonal variability in elemental content, $\delta^{13}C$ and $\delta^{15}N$ of *Thalassia testudinum* from south Florida. Submitted to *Estuaries*.

Rutten, L.M. 2002. An assessment of nearshore benthic communities of the Florida Keys. Masters of Science Thesis, Florida International University, Biology Department.

Ferdie, M. 2002. Nutrient limitation of benthic primary production in the upper Florida Keys. Masters of Science Thesis, Florida International University, Biology Department.

Fourqurean, J.W., and L.M. Rutten. In press. The impact of Hurricane Georges on soft-bottom, backreef communities: site- and species-specific effects in South Florida seagrass beds. *Bulletin of Marine Science*.

Fourqurean, J.W., N. Marbà and C.M. Duarte. 2003. Elucidating seagrass population dynamics: theory, constraints and practice. Limnology and Oceanography 48(5): 2070-2074.

Collado-Vides, L., L.M. Rutten, and J.W. Fourqurean. In review. Spatiotemporal variation of the abundance of calcareous green macroalgae in the Florida Keys: A study of synchrony within a macroalgal functional-form/group. *Journal of Phycology*.

Ferdie, M. and J. W. Fourqurean. In review. Responses of seagrass communities to fertilization along a gradient of relative availability of nitrogen and phosphorus in a carbonate environment. *Limnology and Oceanography*.

U.S. EPA / FKNMS Coral Reef Evaluation and Monitoring Project

Carl R. Beaver, Walter C. Jaap, M.K. Callahan, Jim Kidney, Stopher Slade, Selena Kupfner, and Shannon Wade (Florida Fish and Wildlife Conservation Commission/Fish and Wildlife Research Institute (FWC/FWRI), St. Petersburg, FL)
James W. Porter, Katie Sutherland and Cecilia Torres (University of Georgia, Athens, GA)
Chris Tsokos and George Yanev (University of South Florida, St. Petersburg, FL)

Goal

The Coral Reef Evaluation and Monitoring Project (CREMP) is part of the Water Quality Protection Program for the Florida Keys National Marine Sanctuary (FKNMS). The goal of this project is to utilize broad spatial coverage, repeated sampling, and statistically valid findings to document status and trends of coral communities within the Sanctuary. As coral reef monitoring is integrated with the seagrass and water quality monitoring projects, the results can be used to focus research on determining causality and to fine tune and evaluate management decisions.

Methods

Sampling site locations were chosen in 1994 using a stratified random sampling procedure (U.S. EPA EMAP). Forty reef sites were selected within the FKNMS and permanent station markers were installed in 1995. Annual sampling began in 1996 and has continued through 2002. Three additional sites were installed and sampled in the Dry Tortugas beginning in 1999. The project's 40 sampling sites include four hard-bottom, 11 patch, and 12 offshore shallow and 13 offshore deep reef sites. Each site is composed of two to four stations.

Station Species Inventory (SSI)

SSI consists of counts of stony coral species (Milleporina and Scleractinia) present in each station to provide data on stony coral species richness (S). Two observers conducted simultaneous timed (15 min.) inventories within the 22 x 2 m stations and entered the data on underwater data sheets. Each observer recorded all stony coral taxa and fire corals and enumerated long-spined urchins (*Diadema antillarum*) within the station boundaries. After recording the data, observers compared (5 min.) data underwater and confirmed species recorded by only one observer. Data sheets were verified aboard the vessel and forwarded to FWRI for data entry and processing. This method facilitates data collection with broad spatial coverage at optimal expenditure of time and labor. During the species inventory any species within a station that exhibited specific signs of either bleaching or disease (black band, white complex, and other) was documented on the data sheet.

Videography

All sampling through 1999 was filmed with a Sony CCD-VX3 using full automatic settings. Beginning in 2000, the project upgraded to digital video filming all sites with a SONY TRV 900. To ensure quality images, artificial lights were used when necessary. A convergent laser light system aided the videographer in maintaining the camera at a uniform distance above the reef surface (40 cm). The videographer filmed a clapperboard prior to beginning each transect. This provided a complete record of date and location of each segment recorded. Filming was conducted at a constant swim speed of about 4 m/min. yielding approximately 9,000 video frames per transect. Images for all transects were frame grabbed, and written to and archived on CD-ROM.

Bioeroding Sponge Survey
In 2001, the project began monitoring the abundance and percent cover of bioeroding sponge species. Bioeroding sponge data were collected at all CREMP stations. The three clionid sponge species (*Cliona delitrix*, *C. lampa*, and *C. caribboea*) recorded by CREMP are known to be aggressive coral bioeroders and over growers. Clionid sampling methodology was developed based on existing project station layout. Three 1-m-wide belt transects provided the maximum spatial coverage within each station. A 30-m survey tape marked the center of reference for each transect. A diver delineated the survey area by swimming directly above the tape holding a meter stick perpendicular to the tape and parallel to the reef surface. The location, species, and size of each clionid sponge colony were recorded. The species of stony coral affected by the clionid colony was also recorded. Area was measured by means of a 40-cm by 40-cm quadrat frame subdivided into 5-cm squares. The area occupied by the clionid colony was recorded to the nearest half square.

Stony Coral Population Dynamics
A quantitative survey was performed at nine sites (three in each of the Upper, Middle, and Lower Keys) to provide information on the relative abundance and size classification of individual coral colonies. These data have value for defining both recruitment and community structure. Analyses of these data included relative abundance by size for individual coral species as well as community indices such as species diversity, dominance, and evenness, as well as inferential statistical testing. At each "value-added" site, abundance and size-class distribution data were collected for all stony corals. Twenty 1-m^2 quadrats were surveyed within a sampling station. A 1-m^2 quadrat frame was placed along either side of a centerline that extended between the permanent stakes marking each site. A diver recorded the species and size classification for each species of stony coral within each quadrat. Size classifications were 0-3 cm, 3-10 cm, 10-50 cm, and >50 cm. Size was measured at the point of greatest areal coverage within a colony.

Diseased Coral Survey (DCS)
The DCS was designed to determine whether coral diseases significantly influence the survival of coral in the Florida Keys. This study quantified the abundance and distribution of different diseases on different species of corals. Individual colonies were assessed by annually photographing individual coral specimens at each of the 18 value-added stations in the Florida Keys CREMP. All colonies affected by either bleaching or disease within the 40-m^2 (2 m wide by 20 m long) transect at each station were located and photographed. A digital still camera was used to take two photographs (side view with morbid or bleached area and from above) of affected corals with a clapperboard in the field of view for metadata and scale. The precise position of each colony within a transect was recorded in order to allow its relocation during subsequent resurveying.

Temperature Study
Temperature data were collected to document possible trends of increasing water temperatures within FKNMS sampling sites. Small in situ temperature loggers were installed at all value-

added sites during 2002 and early 2003. These data-loggers recorded water temperature hourly and were recovered, downloaded, and re-deployed quarterly.

Statistical Analyses
Independent consultants conducted statistical analyses of the percent cover, species richness, and disease/condition data. The decision to reject or not to reject the null hypothesis that there was no significant difference in the data for certain years was based on the minimum detectable difference for different significance levels and powers. Combinations for significance level (α) and power (1- β) were considered: α = 0.05, 1-β = 0.75; α = 0.10, 1-β = 0.75. When the one-sided alternative was tested, the above values for α must be divided by two. The output consisted of the minimum detectable difference for a certain pair (α, 1-β), which was used to construct a (1-α) % confidence interval and provided a measure of the test accuracy.

Findings to Date
Results are reported for the regions defined as follows: Upper Keys (North Key Largo to Conch Reef), Middle Keys (Alligator Reef to Sombrero Reef), Lower Keys (Looe Key to Smith Shoal), and Tortugas (Dry Tortugas to Tortugas Banks). In order to make valid comparisons between 2002 data and data from previous years, 1996-2000 data were recalculated using only data from stations that continued to be sampled after station reduction. This report presents data for those 117 stations (105 in Keys proper and 12 in Dry Tortugas). Dry Tortugas data are presented separately because sampling there was not initiated until 1999.

Stony Coral Species Richness
Sanctuary-wide from 1996 to 2002, the number of stony coral species declined at 74 stations (70%), increased at 21 stations (20%), and remained unchanged at 10 stations (10%) (Table 1). In 2002, the project documented a decline in stony coral species number in all habitat types. The offshore deep and patch reef stations had the greatest numbers of stony coral taxa, with 18 and 16 species, respectively. Hardbottom stations contained the fewest, averaging nine species per station.

Table 1. Number of stations with change in stony coral species richness by habitat type, 1996-2002.

	Patch			**Shallow**			**Deep**			**Hardbottom**			**Total**		
Years	No Change	Gain	Loss	No Change	Gain	Loss	No Change	Gain	Loss	No Change	Gain	Loss	No Change	Gain	Loss
96vs97	5	3	21	6	24	9	4	11	11	1	6	4	16	44	45
97vs98	7	13	9	7	10	22	4	4	18	2	4	5	20	31	54
98vs99	7	8	14	6	6	27	5	4	17	1	0	10	19	18	68
99vs00	8	12	9	8	14	17	7	14	5	2	5	4	25	45	35
00vs01	5	11	13	9	17	13	3	9	14	1	7	3	18	44	43
01vs02	6	11	12	8	12	19	5	10	11	1	4	6	20	37	48
96vs02	5	3	21	1	10	28	2	5	19	2	3	6	10	21	74

Between 1996 and 2002, the number of stony coral species declined at 21 of 29 (72%) patch reef stations, increased at three stations, and remained unchanged at five stations (Table 1). For shallow reef stations, the number of stony coral species declined at 28 of 39 (72%), increased at 10 stations, and remained unchanged at one station. The number of stony coral species declined at 19 of 26 (73%) deep reef stations, increased at five stations, and remained unchanged at two stations. For hardbottom stations, the number of stony coral species declined at six of 11 (55%) stations, increased at three stations, and remained unchanged at two stations.

In the Upper Keys from 1996 to 2002, the number of stony coral species declined at 23 of 30 stations (77%), increased at two stations, and remained unchanged at five stations. In the Middle Keys, the number of stony coral species decreased in 20 of 29 stations (69%), increased at seven stations, and remained unchanged at two stations. In the Lower Keys, the number of stony coral species decreased at 31 of 46 stations (67%), increased at 12 stations, and remained unchanged at three stations. In the Dry Tortugas from 1999 to 2002, the number of stony coral species decreased at nine stations and increased at three stations.

Sanctuary-wide, the number of stations where *Acropora cervicornis* and *Scolymia lacera* were present decreased significantly ($\alpha = 0.05$) while the number of stations with *Colpophyllia natans*, *Madracis mirabilis*, *Porites porites*, *Siderastrea radians*, *Mycetophyllia ferox*, and *M. lamarckiana* decreased at the $\alpha = 0.1$ level. Only *Siderastrea siderea* was found at significantly more stations in 2001-2002 than in previous years.

Stony Coral Condition

Diseases were recorded as present or absent for each species at a station. In general, the number of stations documented as having diseased corals increased from 1996 to 2002 (Fig. 1). Overall, the number of stations containing diseased coral, the number of coral species with disease, and the different types of observed diseases all increased.

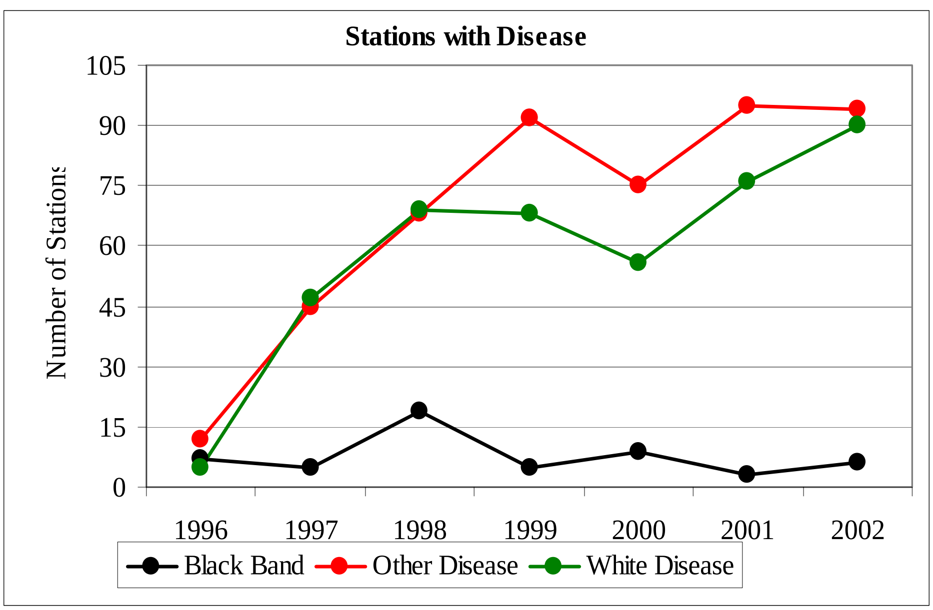


Figure 1. Number of stations with coral disease, 1996-2002.

As in previous sampling periods, black band disease was the least common of the disease categories recorded by the project. The number of stations with black band disease was highest in 1998 (19 of 105 stations). In all other years, black band disease was recorded at less than 10 stations. The species most commonly affected by black band disease were *Colpophyllia natans, Montastraea annularis, M. cavernosa*, and *Siderastrea siderea*.

The occurrence of “white disease” increased from five stations in 1996 to 90 stations in 2002 (Fig. 1). This increase was primarily driven by increases in white disease in *Montastraea annularis* complex, *Agaricia agaricites* complex, *Porites astreoides*, and *Siderastrea siderea* colonies. In 1996, *M. annularis* complex at all CREMP sites were free from white disease. By 2001, *M. annularis* complex at 32 stations were affected.

White disease was not found to have affected any *A. agaricites* colonies during 1996, but by 2001 white disease was observed on *A. agaricites* at 33 sites. This number had decreased to 27 stations in 2002. Incidence of white disease also increased in *P. astreoides* from zero stations in 1996, to six stations in 2001, and then 12 in 2002. The maximum value previously reported was 11 stations observed in 1997. Incidence of white disease in *S. siderea* increased from four stations in 2001 to 21 stations in 2002. The previous maximum occurrence for this species was 12 stations in 1997.

For adequate data for statistical testing, 2001 and 2002 disease data were pooled for comparison with 1996-2000 data. For the pooled 2001 and 2002 data, testing indicated that *Agaricia agaricites* complex, *Montastraea annularis* complex, *M. cavernosa*, *Siderastrea siderea*, and *Stephanocoenia michelinii* were affected by white disease at a significantly greater number of stations than the 1996-2000 data.

For the purpose of hypothesis testing, the “other disease” data for 2001-2002 were pooled and compared with the data from 1996-2000 to determine significant changes in the number of stations where each species was affected by “other disease.” Tests indicated that 14 species had significant increases in the number of stations where “other disease” was detected. These species included: *Agaricia agaricites* complex, *Colpophyllia natans*, *Dichocoenia stokesii*, *Eusimilia fastigiata, Favia fragum*, *Meandrina meandrites*, *Millepora alcicornis, Millepora complanata, Montastraea cavernosa*, *Montastraea annularis* complex, *Porites astreoides, Porites porites, Siderastrea siderea*, and *Stephanocoenia michelinii*.

Pooled data for 2001-2002 were compared with pooled data for 1996-2000 to determine significant differences in the number of sites where bleaching affected each species. Bleaching affected *Agaricia agaricites* complex, *Montastraea annularis* complex, and *Montastraea cavernosa* at an increased number of sites during the 2001-2002 period.

Stony Coral Cover

Between 1996 and 2002, a 38% decline in stony coral cover was observed Sanctuary-wide (Fig. 2). This trend was confirmed by non-parametric hypothesis testing at the Sanctuary level. The decline in mean percent coral cover from 1997 to 1998 and from 1998 to 1999 was significant with a p-value of 0.03 or less for the Wilcoxon rank-sum test. Between 1997 and 1998 coral cover declined from 11.4% to 9.6%. The downward trend continued between 1998 and 1999 when coral cover declined from 9.6% to 7.4%. The changes observed from 1999 to 2002 were determined to be statistically non-significant. Sanctuary-wide coral cover has not changed significantly since 1999.

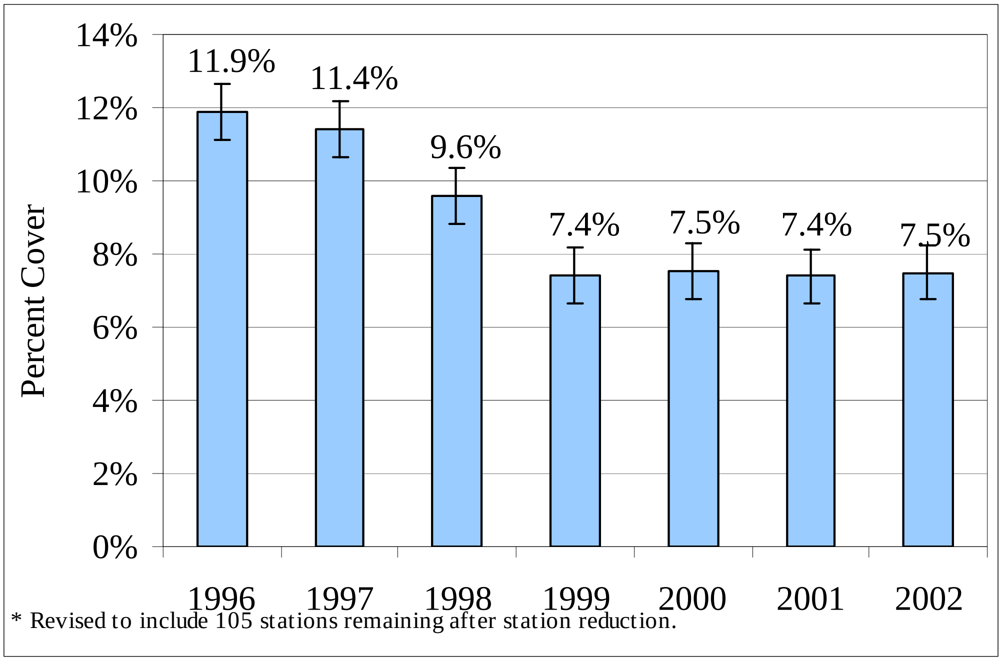


Figure 2. Mean percent stony coral cover Sanctuary-wide, 1996-2002.

At the regional and habitat levels, hypothesis testing compared 2002 coral cover data to pooled 1998-2001 data as well as pooled 1999-2001 data. Regionally, stony coral cover reflected patterns observed Sanctuary-wide. In all three geographical areas, a significant decrease in stony coral cover was observed between 1996 and 1998. Comparisons between 1998-2001 pooled data and 2002 data indicated significant decreases in stony coral cover within the Upper and Lower Keys regions. Comparisons between 1999-2001 pooled data and 2002 data detected no significant differences in stony coral cover for any region.

In the Upper Keys, 18 stations (64%) lost significant coral cover while two stations (7.1%) gained coral and eight stations (28.5%) remained unchanged (Fig. 3).

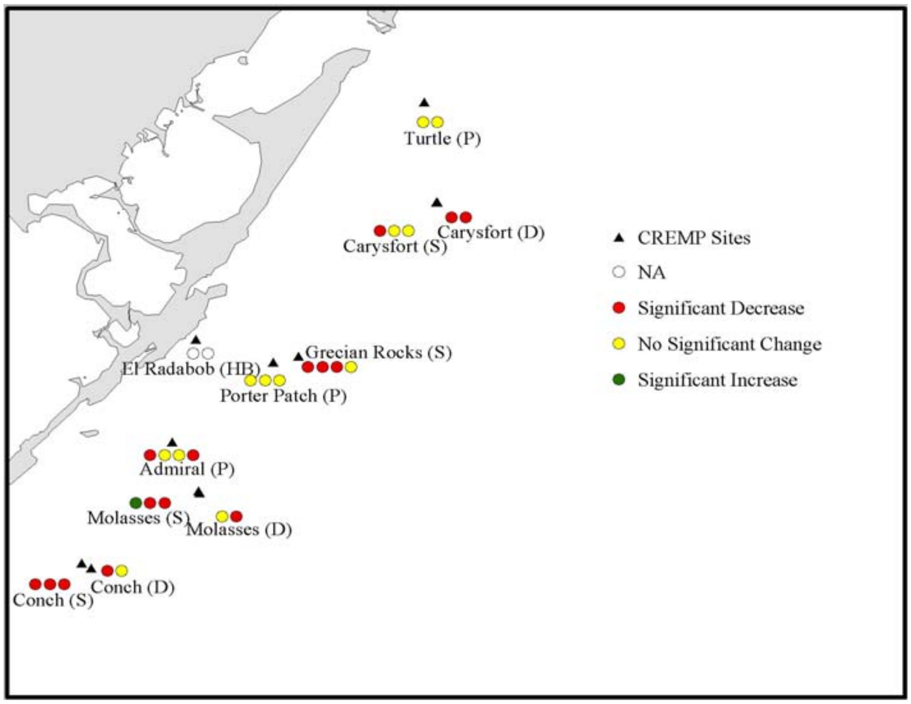


Figure 3. Distribution of significant change in stony coral cover at Upper Keys stations, 1996-2001 vs. 2002.

In the Middle Keys, significant coral cover was lost at 10 (34%) stations, no significant change was seen at 18 (62%) stations, and significant coral cover was gained at one station (Fig. 4).

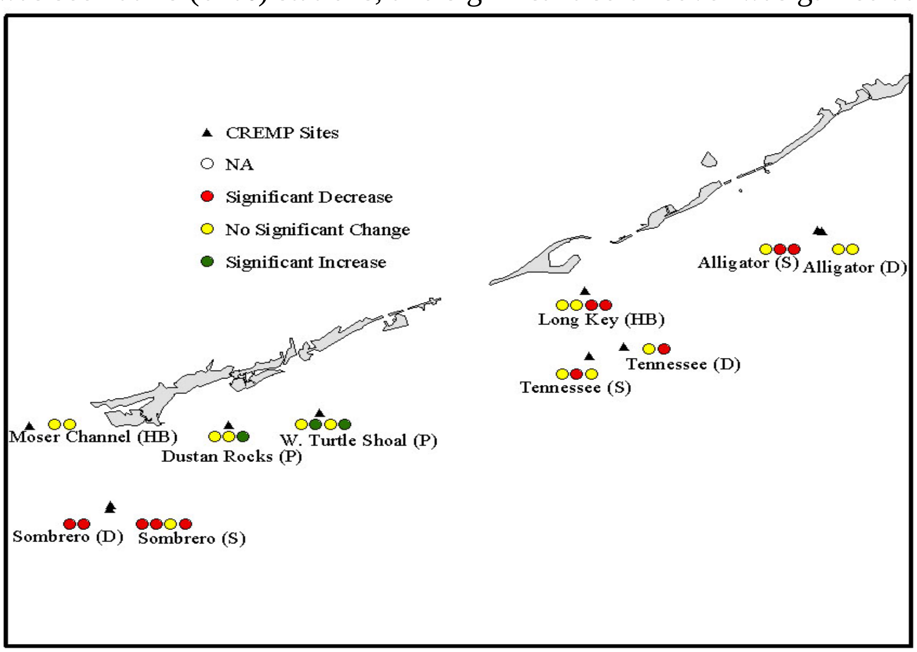


Figure 4. Distribution of significant change in stony coral cover at Middle Keys stations, 1996-2001 vs. 2002.

In the Lower Keys, significant coral cover was lost at 29 (63%) stations, no significant change was seen at 13 (28%) stations, and significant coral cover was gained at four stations (Fig. 5).

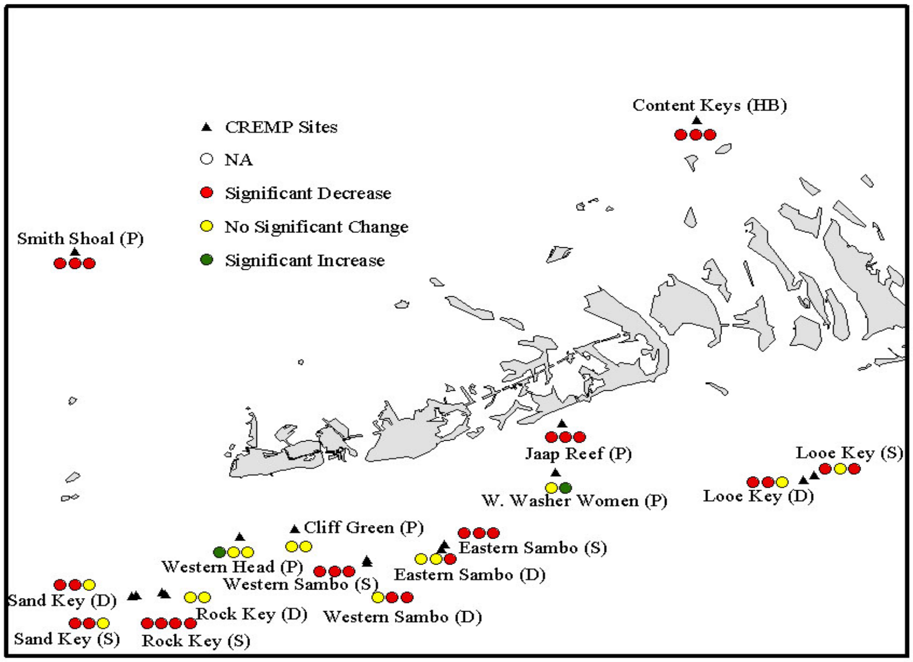


Figure 5. Distribution of significant change in stony coral cover at Lower Keys stations, 1996-2001 vs. 2002.

In the Dry Tortugas in 2002, significant coral cover was lost at eight stations, while no significant change was seen at four stations (Fig. 6).

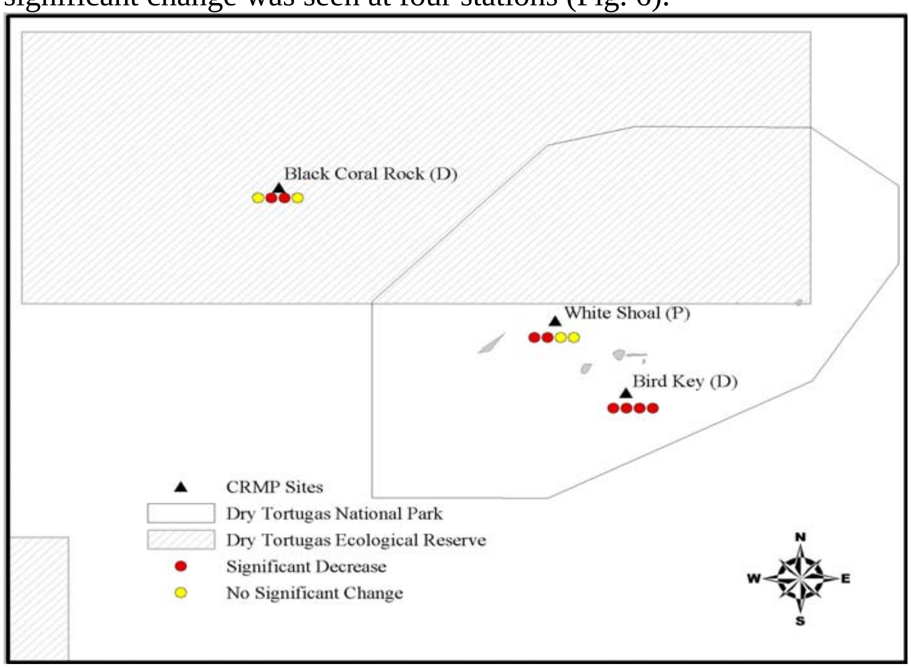


Figure 6. Distribution of significant change in stony coral cover at Dry Tortugas stations, 1999-2001 vs. 2002.

Functional Group Cover

Percent-cover data for functional groups in the geographic regions studied from 1996 to 2002 were analyzed. Functional groups included: stony corals, octocorals, zoanthids, sponges, macroalgae, seagrass, and substrate (rock, rubble, and sediments). In the Upper Keys from 2001-2002, macroalgae and octocoral cover increased slightly, while stony coral and sponge cover remained unchanged. The Lower Keys had a decrease in macroalgal cover and a slight increase in octocoral cover. Stony coral and sponge cover remained unchanged. The Middle Keys had a significant decrease in macroalgal cover and a significant increase in octocoral cover. All other components of the Middle Keys benthic community remained unchanged. Sanctuary-wide, in 2002, the benthic community at CREMP sites was composed of 66.8% substrate, 11.0% octocoral, 9.3% macroalgae, 7.5% stony coral, 2.5% sponge, 2.2% zoanthids, and 0.6% seagrass (Fig. 7).

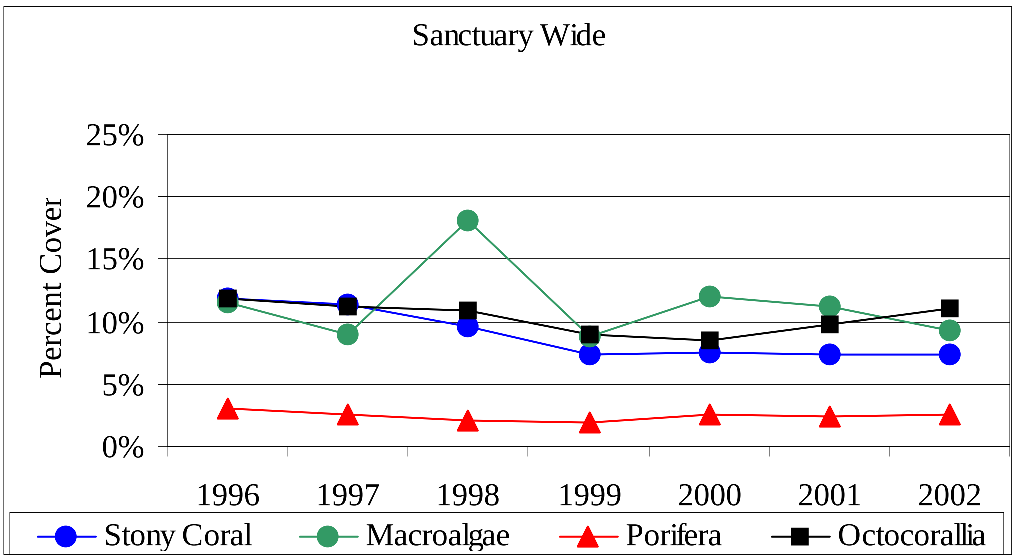


Figure 7. Mean percent cover of functional groups Sanctuary-wide, 1996-2002.

Stony Coral Species Cover

An understanding of the overall trend in stony coral cover can be gained by analyzing the changes in percent cover of the most common species. The six coral species with the greatest mean percent cover Sanctuary-wide in 1996 were *Montastraea annularis* (4.1%), *M. cavernosa* (1.4%), *Acropora palmata* (1.1%), *Siderastrea siderea* (1.0%), *Millepora complanata* (1.0%), and *Porites astreoides* (0.6%). *M. annularis* represented approximately 35% of the coral cover at CREMP stations in 1996. *M. annularis* decreased from 4.1% in 1996 to 2.7% in 2002 (a 34% reduction). *M. cavernosa* decreased from 1.4% in 1996 to 1.3% in 2002.

Although *Acropora palmata* (elkhorn coral) only occurs in offshore reef habitats sampled, and comprised only 1.1% of mean coral cover in 1996, it is well recognized as a primary framework species. Striking changes were documented for this species as well as *A. cervicornis* (staghorn coral) and *Millepora complanata*, the once-dominant, shallow reef, bladed fire coral. The mean percent cover of *A. palmata* decreased 91% from 1.1 in 1996 to 0.1 in 2002. Between 1996 and

2002 percent cover of *A. cervicornis* decreased 94%, from 0.20 to a barely detectable 0.01. Also, between 1996 and 2002 percent cover of *M. complanata* declined from 1% to 0.03%.

Bioeroding Sponge Data

In 2002, the mean area of clionid sponge cover was greatest at patch reef stations in the Lower Keys. In the Upper Keys, the number of clionid colonies decreased at all stations except deep ones. The greatest average number of colonies was seen at Upper Keys deep stations (109) followed by Lower Keys deep stations (53), and then Lower Keys patch reef stations (44). At Content Keys, the mean number of clionid colonies decreased from 35 in 2001 to zero in 2002. Likewise, at Smith Shoal the average number of clionid colonies decreased from 46 in 2001 to zero in 2002.

Value-Added Station Sampling

Diseased Coral Survey (DCS)

Overall, 323 diseased coral colonies of 22 different species were recorded at 18 stations in 2002. A total of 12 known coral diseases, and bleaching, affected coral colonies at CREMP value-added sites. Eleven species were most commonly affected by coral disease (Fig. 8).

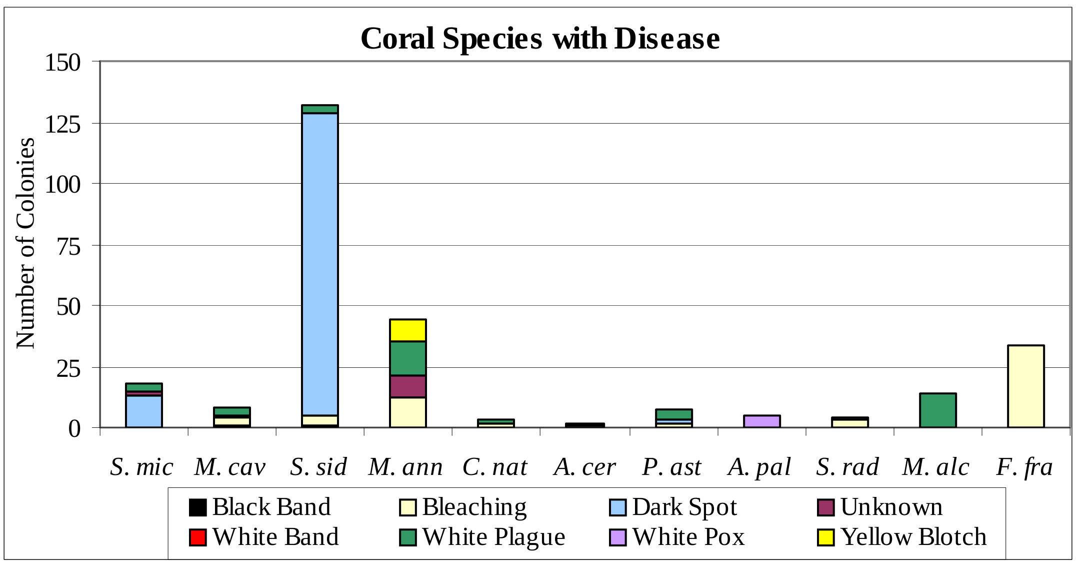


Figure 8. Number of colonies of selected coral species affected by disease within CREMP value-added sites during 2002.

Siderastrea siderea and *Montastraea annularis* were both affected by four diseases, while both *Stephanocoenia michelinii* and *M. cavernosa* were affected by three diseases each. All others were affected by two or fewer diseases. *Siderastrea siderea* was most commonly affected by what has been termed “dark spot” disease. It should be noted that although this malady was very common during the 2002 sampling period, “dark spot” disease had virtually disappeared from Middle Keys value-added stations by June 2003.

Black band, white plague, bleaching, and an unknown malady affected *M. annularis* complex colonies. In addition to *M. annularis* colonies, bleaching affected *M. cavernosa*, *S. siderea*, *S. radians*, *Colpophyllia natans*, *Porites astreoides*, and *Favia fragum*.

Preliminary review of the data indicated widespread existence of coral disease among nearly all coral species recorded at CREMP value-added stations. Cases of infection by all of the Caribbean coral diseases that can be distinguished underwater were identified.

Stony Coral Population Dynamics
Coral abundance was assessed at all 18 value-added stations (VAS). A wide range of community indices was calculated from VAS species data. Species richness ranged from seven to 26 while species diversity (H') ranged from 0.82 to 2.51. Abundance values also varied greatly, ranging from 18 colonies at Grecian Rocks station 2 to over 500 colonies at Cliff Green station 4.

The typical coral community at a CREMP value-added station contained 176 colonies representing 13 coral species. Twenty-two percent of coral colonies were in the 0-3 cm size class while 46% of colonies were 3-10 cm, 26% of colonies were 10-50 cm, and 10% were over 50 cm.

Siderastrea sp. had the greatest mean number of colonies in the 0-3 cm, 3-10 cm, and 10-50 cm size classes with 19.6, 16.4, and 9.1 colonies per station, respectively. Other common corals in the 3-10 cm size class included *M. alcicornis* (mean 13.52 colonies/station), *Stephanocoenia michelinii* (mean 13.27 colonies/station), and *Agaricia agaricites* (mean 3.27 colonies/station). In addition to *Siderastrea* sp., common corals in the 10-50 cm size class included *S. michelinii* (mean 7.35 colonies/station), *Porites astreoides* (mean 4.15 colonies/station), and *M. alcicornis* (mean 3.48 colonies/station). The most common coral species over 50 cm included *Montastraea annularis* (mean 3.04 colonies/station) *Colpophyllia natans* (mean 2.83 colonies/station), and *M. cavernosa* (mean 2.52 colonies/station).

Discussion and Conclusions
From its inception in 1996, the Coral Reef Evaluation and Monitoring Project (CREMP) has documented long-term changes in the status and trends of coral reefs throughout the 9,844-km^2 FKNMS. The data set produced from this monitoring effort has been, and will continue to be, an indispensable asset for sound resource management decisions. Between 1996 and 2002, the project reported a 38% reduction in stony coral cover sanctuary-wide. A steep decline in percent cover of stony corals was documented between 1997 and 1999. From 1999 to 2002, the percent cover of stony corals has remained essentially unchanged.

Hypothesis testing has revealed a significant loss in stony coral cover at 55% of project stations while only 7% showed a significant increase. By region, the Upper Keys experienced the greatest decline with significant loss in coral cover at 64% of stations, followed by the Lower Keys with loss at 63%, and the Middle Keys with a loss at 34% of stations. The greatest declines in coral cover occurred between 1996 and 1999. Coral cover declined from 11.9% in 1996 to 7.4% in 1999. Since 1999, percent cover at CREMP sites varied less than 0.1% per year. Statistical analysis has determined no significant difference in percent coral cover between 1999 and 2002, suggesting a halt in the decline of coral cover. This halt in coral decline has been recognized elsewhere as well. Wilkinson (2002) suggested that other reefs that showed severe declines in coral cover during the 1997-1998 bleaching event have shown slow to moderate signs of recovery.

Evidence such as the loss of hard corals, increased abundance of algae, and a dramatic increase in bleaching episodes and disease outbreaks are indications that coral reefs are deteriorating worldwide. The U.S. Coral Reef Task Force (http://coralreef.gov/threats.cfm) cites population increases, shoreline development, increased sediments in the water, trampling by tourists and divers, ship groundings, pollution, overfishing, and fishing with poisons and explosives that destroy coral habitat as some of the major anthropogenic threats to corals worldwide. These stresses act separately and in combination with natural factors such as hurricanes and disease to degrade reefs. Further, recent research supports a link between coral disease and anthropogenic stressors (Harvell et al. 1999; Porter et al. 1999; Shinn et al. 2000; Harvell et al. 2001; Porter et al. 2001; Patterson et al. 2002). These threats and others have contributed to an estimated 21% loss of coral reefs worldwide in 2000 (http://www.aims.gov.au/pages/research/coral-bleaching/scr2002/scr-00.html). The major emphasis of coral reef research worldwide is to identify the causes of coral decline and assess the synergistic impact of these causes on global, regional, and local scales.

On a regional scale, the 105 CREMP stations are downstream of much of the Caribbean basin, the Gulf of Mexico, the Everglades, and Florida Bay. The interaction between these upstream regimes and the Florida Keys varies in magnitude and on many time scales. On a local scale, the 105 CREMP stations are subdivided into four habitat types based on depth, distance from shore, and biotic character. Hardbottom, patch reefs, shallow offshore reefs, and deep offshore reefs each have characteristic sets of stony coral species and relative percent cover. As such, we expect coral reefs in the Florida Keys to respond to stress on multiple scales of space and time.

Since the beginning of the CREMP in 1996 a series of stress events, occurring in quick succession, appear to be responsible for the most recent declines in coral cover and species diversity. Global bleaching events in 1997 and 1998 were severe to moderate and resulted in increased stress, instigating morbidity and mortality in some cnidarian species. Elevated water temperatures were thought to be the cause of high mortality in *Millepora complanata* in Lower and Middle Keys offshore shallow reefs during this period. Although short lived, hurricanes can cause significant adverse affects to the coral reef community on regional and local scales. Gardner (2002) claimed that Florida reefs historically exhibited an average 6.5% loss in coral cover within one year of the occurrence of a hurricane. Hurricane Georges, which hit the Keys in 1998, resulted in coral losses of up to 44% at some locations (J. Dotten, pers. comm.).

The decline in coral cover observed on Florida reefs is similar to declines reported for reefs elsewhere in the Caribbean and Gulf of Mexico. Linton et al. (2002) reported that coral cover in the Bahamas has declined from 9.6% in 1994 to 4.0% in 2001. Bermuda reefs have displayed less precipitous declines with coral cover decreasing from 23% in 1993 to 18% in 2001. Coral cover in the Cayman Islands has also declined in recent years. Department of Environmental Protection and Conservation Unit data showed that Little Cayman reef corals declined from 23% in 1997 to 16% in 2001. On Grand Cayman, coral cover declined from 25% in 1997 to 15% in 2001 (Linton et al. 2002).

Reefs of the western Caribbean and the southern Gulf of Mexico have exhibited some of the greatest losses in coral cover in recent years. Major disturbances such as Hurricane Mitch in

1998 and Hurricanes Keith in 2000, Iris in 2001, and Isidore in 2002 have had major impacts on reefs along Belize, Honduras, and the Mexican Yucatan. Belize alone reportedly a loss of up to 75% coral cover on some reefs (Almanda-Villela et al. 2002). This series of hurricanes and the resultant flooding and sedimentation, and an increase in coral disease and bleaching, are expected to have long-term ecological consequences (Almanda-Villela et al. 2002).

The recovery of damaged corals appears to have slowed significantly in recent years. The impact of hurricanes on coral reefs is largely separate from the suite of anthropogenic stressors, but these anthropogenic stressors affect the recovery of reefs following physical disturbance events. The absence of post-hurricane recovery on CREMP stations is one of dozens of such observations in the Western Atlantic. A synthesis of coral monitoring data (Connell 1997) found no clear examples of reef recovery following disturbances of any kind. Connell (1997) did find 17 clear examples of coral decline in the Western Atlantic with no subsequent recovery. This sharply contrasts with reefs of the Indo-Pacific where Connell (1997) found 19 clear examples of coral decline with recovery, and 10 examples of decline with no recovery.

It is important to note that declines in coral cover and numbers of species are not necessarily a recent phenomenon and are likely the result of multiple, chronic and acute stressors acting at local, regional, and global scales over long periods. The shifting-baseline phenomenon emphasizes the importance of viewing recent CREMP results in the context of long-term dynamics in the Florida Keys.

For example, during the 1960s and 1970s, *Acropora* populations exhibited boom and bust dynamics. Populations would expand and occupy virtually all of the potential space on a reef such as Western Sambo. Spur-and-groove areas were densely populated with large and moderate-sized colonies of *Acropora palmata*, while the fore reef and back reef supported dense thickets of *Acropora cervicornis*. Populations that suffered extensive destruction from Hurricanes Donna and Betsy appeared to have recovered within five years.

In 1975 there were hectares of *A. cervicornis* within Dry Tortugas National Park, so much so that it was difficult to navigate in the area west of Loggerhead Key because *A. cervicornis* had grown upward to near sea level (Davis 1982). In late 1977 and early 1978, a severe winter cold front reduced the temperature to about 14°C and virtually all of the *A. cervicornis* was extirpated due to hypothermia. In 1981, a disease epidemic further reduced *A. cervicornis* populations to a minor component of the Florida Reef Tract (Jaap et al. 1989).

With reduced coral cover, high temperatures, and perhaps increased nutrients, marine algae expanded rapidly in the mid 1990s. Ideally, algal control occurs as the result of grazing by herbivores and storm events. However, throughout much of the Caribbean herbivore populations have been reduced due to disease and overfishing. The long-spined sea urchin *Diadema antillarum* is known to be an important algal grazer, but populations of this species have yet to recover from a Caribbean-wide die-off, which occurred in 1983. CREMP data show that macroalgae percent cover is more variable than other benthic biota. Despite the substantial reductions in herbivore populations, percent cover of macroalgae has not increased from 1996 to 2002. These results suggest that macroalgae are not limiting coral recovery of Keys reefs.

Future Direction

The health of coral reefs of the Florida Keys is dependent on the quality of water along the reef tract. Because of the sensitive nature of corals, even slight changes in water quality can prove stressful for the reef. The Florida Reef Tract is under constant threat from terrestrial impacts far from the reef habitat. Extensive agricultural areas and channelization in central and southern Florida may adversely affect the quality and quantity of water delivered to the Florida Everglades and Florida Bay. As water quality is impacted by changes in the volume of water delivered to Florida bay, reefs may decline in channel areas based on similar experiences in other locations (Tomascik and Sanders 1985; Richmond 1993; Furnas and Mitchell 2001; Geister 2001).

The Comprehensive Everglades Restoration Plan (CERP) aims to re-establish the historical flow of water through south Florida and Florida Bay. This massive project will inevitably alter biological communities and water quality in Florida Bay. Downstream of Florida Bay, the Florida Keys reef tract provides the last opportunity to quantify CERP-induced changes. Therefore, continued monitoring is crucial in order to document status and trends of coral reefs in the FKNMS. In addition to the ongoing monitoring, the CREMP will expand its sampling strategy to better understand causes of coral decline and effects of multiple stressors.

The CREMP will continue non-consumptive sampling at established sites from Key Largo to Tortugas Banks to document status and trends of the coral reef ecosystem. The project will continue to collect a comprehensive suite of indicators at nine of the established 40 sites. These additional indicators will consist of a Diseased Coral Survey (DCS), stony coral abundance survey, temperature measurements, rugosity measurements, and human enterovirus study. The DCS will quantify the abundance and distribution of different diseases. By following the fate of a select number of individual coral colonies, the CREMP will better understand coral community dynamics and mortality rates associated with individual stressors.

The comprehensive monitoring data set on stony coral cover, species richness, bleaching, disease, bioeroders, temperature, fate tracking, human enteroviruses, and abundance will assist in development of landscape-seascape program models to characterize physical, chemical, and biological stressors. Not only will these data assist managers in determining if the fully protected Tortugas Ecological Reserve and Sanctuary Preservation Areas (SPAs) are functioning to protect sensitive resources. They will also provide definitive feedback on downstream effects of the CERP.

This report is a product of the Fish and Wildlife Research Institute pursuant to U.S. EPA grant award number X-97468002-0, and NOAA grant award number NA16OP2554. The complete CREMP Executive Summary for 2002 may be found at:
http://www.floridamarine.org/features/view_article.asp?id=21400.

Acknowledgments
Lauri MacLaughlin, John Halas, Steve Baumgartner, Ben Haskell (FKNMS), Gary Collins, Fred McManus (EPA), Larry Pugh (NOAA/COP), Dale Griffin (USGS), Erin Lipp (UGA), Bob Zepp (NPS), Dry Tortugas National Park Staff. Statistical Consultants: Dr. Chris Tsokos, Dr. George Yanev.

References

Almada-Villela, P., M. McField, P. Kramer, P.R. Kramer, and E. Arias-Gonzalez. 2002. Status of coral reefs of Mesoamerica - Mexico, Belize, Guatemala, Honduras, Nicaragua and El Salvador. Pages 303-323 *in* C. Wilkinson (ed). Status of the coral reefs of the world: 2002. Global Coral Reef Monitoring Network, Australian Institute of Marine Science. http://www.aims.gov.au

Connell, J.H. 1997. Disturbance and recovery of coral assemblages. Coral Reefs 16: S101-113.

Davis, G.E. 1982. A century of change in coral distribution at Dry Tortugas: a comparison of reef maps from 1881-1976. Bull Mar. Sci. 32(2): 608-623.

Furnas, M., and A. Mitchell. 2001. Runoff of terrestrial sediment and nutrients into the Great Barrier Reef World Heritage Area. Pages 37-52 *in* E. Wolanski (ed). Oceanographic processes of coral reefs. Academic Press, Orlando, FL.

Gardner, T. 2002. Coral reefs of the tropical western Atlantic: A quantitative summary of recent temporal change and the relative importance of hurricane impacts. M.S. Thesis. University of East Anglia, Norwich. 77 pp + appendices.

Geister, J. 2001. Coral life and coral death in a recent Caribbean coral reef: a thirty-year record. Bull. Tohoku Univ. Mus. 1: 114-124.

Harvell, C.D., K. Kim, J.M. Burkholder, R.R. Colwell, P.R. Epstein, J. Grimes, E.E. Hofmann, E.K. Lipp, A.D.M.E. Osterhaus, R.M. Overstreet, J.W. Porter, G.W. Smith, and G.R. Vasta. 1999. Emerging marine diseases: Climate links and anthropogenic factors. Science 285: 1505-1510.

Harvell D., K. Kim, C. Quirolo, J. Weir, G. S. 2001. Coral bleaching and disease: Contributors to 1998 mass mortality in *Briareum asbestinum* (Octocorallia, Gorgonacea). Pages 97-104 *In* J. W. Porter (ed). The ecology and etiology of newly emerging marine diseases. Hydrobiologia pp 97-104.

Jaap, W.C., W.G. Lyons, P. Dustan, and J.C. Halas. 1989. Stony coral (Scleractinia and Milleporina) community structure at Bird Key Reef, F. Jefferson National Monument, Dry Tortugas, Florida. Fla. Mar. Res. Publ. 46. 31 pp.

Linton, D., R. Smith, P. Alcolado, C. Hanson, P. Edwards, R. Estrada, T. Fisher, R. Gomez Fermandez, F. Geraldes, C. McCoy, D. Vaughn, V. Voegeli, G. Warner, and J. Weiner. 2002. Status of coral reefs in the northern Caribbean and Atlantic Node of the GCRMN. Pages 277-302 *in* C. Wilkinson (ed). Status of the coral reefs of the world: 2002. Global Coral Reef Monitoring Network. Australian Institute of Marine Science. http://www.aims.gov.au

Patterson, K.L., J.W. Porter, K.B. Ritchie, S.W. Polson, E. Mueller, E.C. Peters, D.L. Santavy, and G.J. Smith. 2002. The etiology of white pox, a lethal disease of the Caribbean elkhorn coral, *Acropora palmata*. Proc. Nat. Acad. Sci. 99: 8725-8730.

Porter, J.W., P. Dustan, W.C. Jaap, K.L. Patterson, V. Kosmynin, O.W. Meier, M.E. Patterson, and M. Parsons. 2001. Patterns of spread of coral disease in the Florida Keys. Pages 1-24 *In* J.W. Porter (ed). The ecology and etiology of newly emerging marine diseases. Hydrobiologia, pp 1-24.

Porter, J.W., S.K. Lewis, and K.G. Porter. 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and a physiological test. Limnol. Oceanogr. 44: 941-949.

Richmond, R.H. 1993. Coral Reefs: present problems and future concerns resulting from anthropogenic disturbance. Amer. Zool. 33: 524-536.

Shinn, E.A., G.W. Smith, J.M. Prospero, P. Betzer, M.L. Hayes, V. Garrison, and R.T. Barber. 2000. African dust and the demise of Caribbean coral reefs. Geophys. Res. Lett. 27: 3029-3032.

Tomascik, T., and F. Sander. 1985. Effects of eutrophication on reef building corals. Mar. Biol. 87: 143-155.

Wilkinson, C. (ed). 2002. Status of the coral reefs of the world: 2002. Global Coral Reef Monitoring Network, Australian Institute of Marine Science. http://www.aims.gov.au

Marine Ecosystem Event Response and Assessment (MEERA) Project

Erich Bartels and Erich Mueller (Mote Marine Laboratory, Tropical Research Laboratory, Summerland Key, FL)

Goals

Initiated in late summer, 1997, as the Rapid Biotic Assessment (RBAT) Project, this project was originally funded by the FKNMS and designed to provide an early warning and assessment program for biotic events on reefs throughout Sanctuary waters. In December, 1999, the project was renamed the Marine Ecosystem Event Response and Assessment (MEERA) Project to more accurately portray the overall scope and objectives of the project, which include any event that impacts the marine environment of the FKNMS and surrounding waters.

Methods

The Marine Observer Network continues to be the most important component of the MEERA project, whereby anyone can call, e-mail, fax, or file a report on-line to submit observations to the MEERA Project Coordinator for evaluation. Public outreach efforts have expanded to reach as large and diverse an audience as possible, including the following:

Fishing Guides	FWC/Fish & Wildlife Research Institute	The Nature Conservancy
Charter Captains	Florida Keys National Marine Sanctuary	Seacamp
Dive Operators	Sanctuary Law Enforcement	U.S. Coast Guard
Commercial Fishermen	National Marine Fisheries Service	U.S. Fish and Wildlife Service
Tropical Fish Collectors	The Ocean Conservancy	All Keys Residents

Findings to Date

A total of 143 reports were received in 2002 from sources including a variety of researchers, State and Federal personnel, and residents, as well as fishers and divers (Table 1). Due to multiple observations included in some reports, a total of 310 observations were logged that included mainly reports of algal blooms and discolored water, sea turtle strandings, coral disease and bleaching, and fish disease or fish kills (Table 2). Other reports included various mortality events, invasive species, and various unusual observations.

Response efforts included the collection, analysis, and shipping of samples; photo-documentation of reports or events; and providing assistance or logistical support for other researchers and organizations. Efforts utilized a combination of volunteers, cooperative agency work, and Mote Marine Laboratory staff and equipment. These efforts included the following:

- Coordinated volunteers to collect water samples during algal blooms or periods of significant water discoloration to assist FWC and Mote Marine Laboratory's Harmful Algal Bloom Monitoring projects.
- Responded to turtle-stranding reports to recover specimens and provide relevant data to the Florida Sea Turtle Stranding and Salvage Network (FWC).
- Investigated several local fish kills affecting canals on Cudjoe Key and Big Pine Key to determine cause and provide information to the FWC Aquatic Health Network.
- Provided logistical support and collaborative efforts on a variety of related research projects (Table 3).

Future Plans

As the project continues to log hundreds of observations each year, there is a clear indication that Marine Observer participation continues to play a crucial role in detecting marine events, and that there is a significant need for increasing response efforts in the future. Several goals have been identified as necessary to increase the MEERA Project's effectiveness:

- Find a source of continued funding to continue expanding the Marine Observer Network and initiate comprehensive response efforts that incorporate increased community participation.
- Continue to improve communication with State and Federal agencies, and other researchers to maximize MEERA's involvement and assistance with response efforts.
- Further develop the MEERA website (www.mote.org/Keys/TRL_MEERA.htm) to allow researchers, resource managers, and the public to access recent reports and submit reports on-line.

Acknowledgment

Funded by the U.S. Fish and Wildlife Service.

Table 1. Types of observations.

Observations	
Algal Blooms/Discolored Water	105
Marine Mammal/Turtle Stranding	77
Coral Disease/Bleaching	35
Fish Disease/Fish Kill	27
Mortality Event	25
Other Observations	41
Total	310

Table 2. Sources of reports.

Report Sources	
Researcher	72
Resident	34
Fish/Dive Industry	20
Web	7
Media	6
Others	4
Total	143

Table 3. Related research supported by Mote's Tropical Research Lab in 2002.

Project	Objectives
Cornell Univ.- Sea Fan Studies	Conduct laboratory and field studies investigating sea fan diseases
Univ. of S. Georgia-Coral Research	Assist with coral collections and growth/spawning experiments
EPA-Special Studies	Study effects of reef fish feeding on coral disease distribution
NOAA CCEMBR-White Plague	Collect samples of infected corals for biomarker analysis
Univ. of Houston-Coral Research	Assist coral transplantation and sampling for genetic study
Harmful Algal Bloom Monitoring	Conduct regular water sampling and respond to HAB events
Coral Disease Workshop	Laboratory and field training related to coral disease research
EPA-UV and CDOM Monitoring	Study CDOM sources and sinks and UV penetration over reefs
EPA-Coral Disease Surveys	Monitor coral disease and bleaching in Florida Keys and Bahamas

Marine Zone Monitoring Program

Ecological Processes and Coral Reef Recovery in the Florida Keys

Struan R. Smith (Bermuda Biological Station for Research, Inc., St. George's GE01, Bermuda)
Richard B. Aronson and Thaddeus Murdoch (Dauphin Island Sea Lab, Dauphin Island, AL)
John C. Ogden (Project Director) (Florida Institute of Oceanography, St. Petersburg, FL)

Goals

The primary purpose of this continuing study of ecological processes and ecosystem function is to evaluate the relationships among coral cover, coral recruitment, and juvenile mortality in fully protected ("no-take") zones and adjacent reference sites in the Florida Keys National Marine Sanctuary (FKNMS). The initial set of fully protected marine zones (FPMZs) consisted of South Carysfort (Carysfort Sanctuary Preservation Area [SPA]) in the Upper Keys, and Eastern Sambo Research Only Area (ROA) and Western Sambo Ecological Reserve (ER) in the lower Keys. The initial reference sites were Maitland, located near the *M/V Maitland* ship-grounding site in the Upper Keys, and Middle Sambo Reef and Pelican Shoal in the lower Keys. These sites have been monitored since 1998, and those efforts continued in 2002. New monitoring sites were established in the Upper Keys in 2002, at the Molasses Reef SPA. Nearby Pickles Reef was selected as a reference area. The expansion of the study was considered necessary for a more representative assessment of the efficacy of FPMZs.

Findings to Date

Coral Reef Community Structure (Aronson and Murdoch)

The study sites were videographically monitored for the sixth year, in late September-early October 2003, to assess the cover of components of the sessile biota (corals, gorgonians, and sponges). Ten randomized video transects were sampled at each shallow and deep site. Analysis of the 2002 data was completed, and analysis of the 2003 data is nearing completion.

Coral cover remained consistently different between sites from 1998 to 2002 (Fig. 1). As in previous years, the Western Sambo ER shallow site exhibited considerably higher cover than the other shallow sites. Substantial declines in coral cover were detected at Western (ER), Middle (reference), and Eastern Sambo (ROA) Reefs from 2001 to 2002; further monitoring will reveal whether those one-year declines represent real signals. Coral species richness was consistent within sites over the monitoring period, as was the cover of sponges. The cover of encrusting octocorals (*Erythropodium caribbaeorum* and *Briareum asbestinum*) increased at all shallow and deep sites from 2000 to 2001, and this trend continued at most sites from 2001 to 2002. The cover of sponges also increased from 2001 to 2002 at all shallow sites.

The effects of year, protection status, and depth were assessed statistically using three-way analysis of variance (ANOVA) designs. Prior to ANOVA, the assumptions of parametric statistics were tested and the data were transformed as necessary. For coral cover, gorgonian cover, and sponge cover, significant interaction terms made interpretation of the ANOVAs problematic.

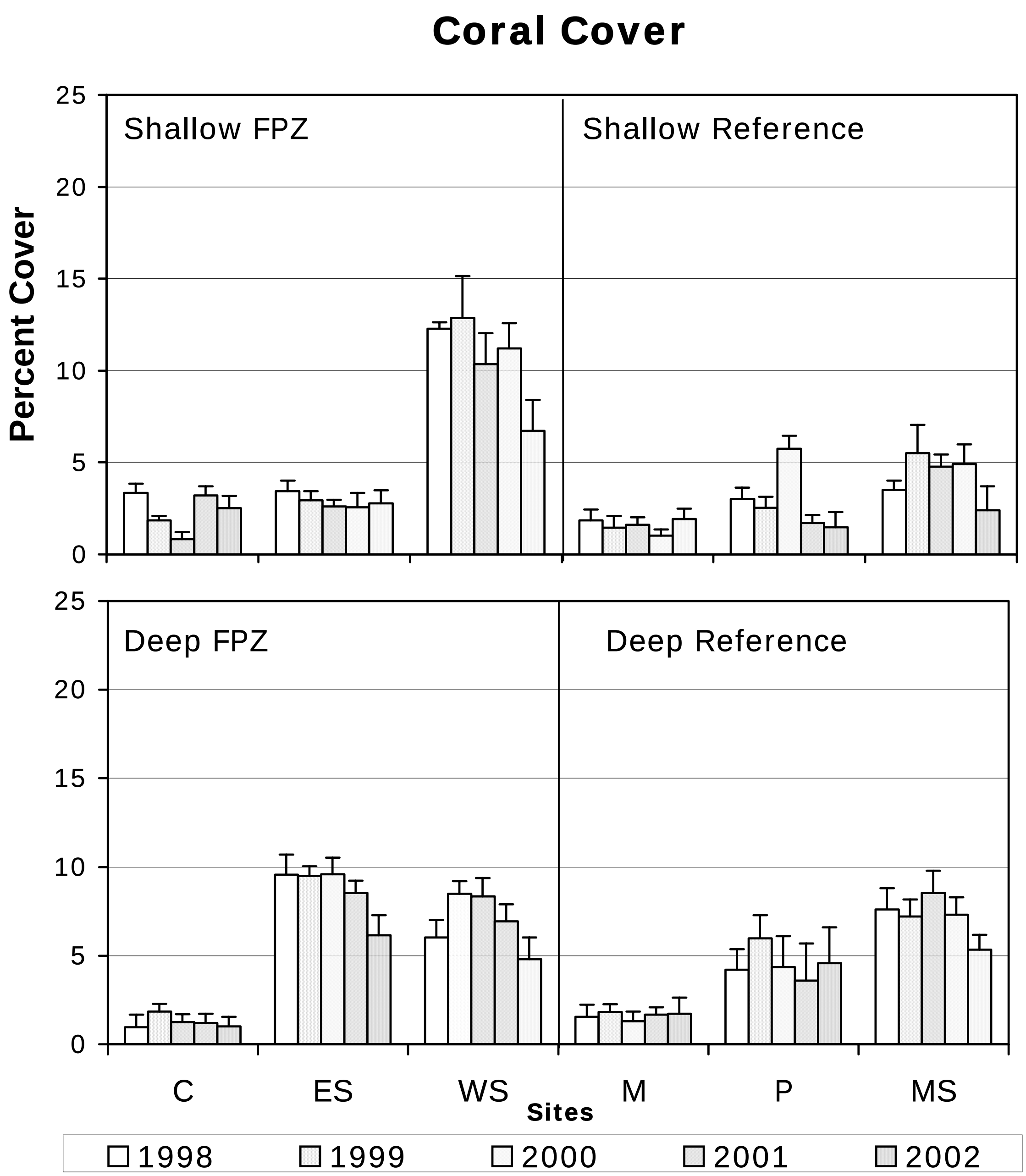


Figure 1. Coral coverage from 1998 to 2002. Mean values are shown with standard error bars. Site codes for Fully Protected Marine Zones (FPZ) are: W = Western Sambo ER, E = Eastern Sambo ROA, C = Carysfort SPA. Site codes for the reference areas are: MS = Middle Sambo, P = Pelican Shoal, M = Maitland.

The transect data were ordinated by multidimensional scaling (MDS) to search for patterns in species composition of the coral assemblages at the sites. Community composition was quite similar at all sites/depths from 2001 to 2002. In the shallow depth range, *Siderastrea siderea* and *Millepora alcicornis* increased at all sites while *Montastraea* spp. (the *M. annularis* species complex and *M. cavernosa*) and *Meandrina meandrites* decreased or remained static at all sites. *Porites porites* increased at two of the three FPMZs and declined at two of three reference sites.

In terms of functional groups, broadcast-spawning, massive coral species have declined dramatically over the years at most sites. Branching species that brood planulae have declined slightly at all sites. Brooding, massive corals have increased in the Upper Keys and declined in Lower Keys sites but only on the reference reefs. In a separate MDS ordination, the deep sites showed a different pattern. They clustered by sector of the reef tract, with sites in the Lower Keys set apart from sites in the Upper Keys, reflecting the lower cover and diversity of corals at the latter sites.

Coral Population Dynamics (Smith)
The recruitment and mortality of juvenile corals were monitored in sets of 32 permanent quadrats established within the initial FPMZs and reference sites from 2001 to 2002 within two depth ranges: shallow, 6-9 m, and deep, 16-18 m. Prepared annotated photographic images of each quadrat from 2001 were used to resurvey the quadrats in situ in 2002, facilitating rapid assessment of changes in the extant corals and occurrence of new corals. This was the fourth period of annual changes observed in the juvenile coral populations since the project began in 1998. QA/QC of 2002 data is mostly complete. Further data are required to verify species-specific patterns of recruitment. The 2003 data are needed to verify provisional identification of some recruits observed in 2002. All corals are entered into a custom Access database.

Permanent quadrats at the shallow depths at the new study sites at the Molasses Reef SPA and Pickles Reef (reference) were established in 2002. However, no data on recruitment and mortality rates will be available until the re-survey in 2003. There appeared to be significantly more juvenile corals present at Pickles reference sites than at the Molasses SPA. There was not sufficient time to establish deep site quadrats in 2002 and that work will be done in 2003.

Coral Recruitment Patterns
After five years of assessment, coral recruitment patterns are showing some clear patterns between depths and between regions in the Florida Reef Tract (Fig. 2). There appear to be very few indications that FPMZs have higher coral recruitment than adjacent reference sites. Only the Western Sambo ER shallow site has shown consistently higher coral recruitment compared to the shallow reference site at Middle Sambo, even though the former site has showed a steady decline in recruitment since 2000. In contrast, recruitment rates at the Pelican deep reference site have been consistently and significantly higher than the adjacent Eastern Sambo ROA.

Shallow sites in both the Lower and Upper Keys have had nearly uniform recruitment rates of three to five new colonies/m^2/yr, with the exception of the Western Sambo ER shallow site, which has had recruitment of about 10 colonies/m^2/yr since 2000. Recruitment has increased steadily at deep sites in the Lower Keys since 2000. Three of the four lower Keys deep sites had significantly higher recruitment rates in 2003 compared to the previous year, with only the Middle Sambo reference site showing no increase from 2002. The overall impression is that recruitment is highly site-specific, with an indication of higher recruitment at Lower Keys deep sites.

The greatest distinctions in recruitment rates appear to be between the Upper and Lower Keys. Recruitment rates have been consistently and significantly lower at both depths in the Upper

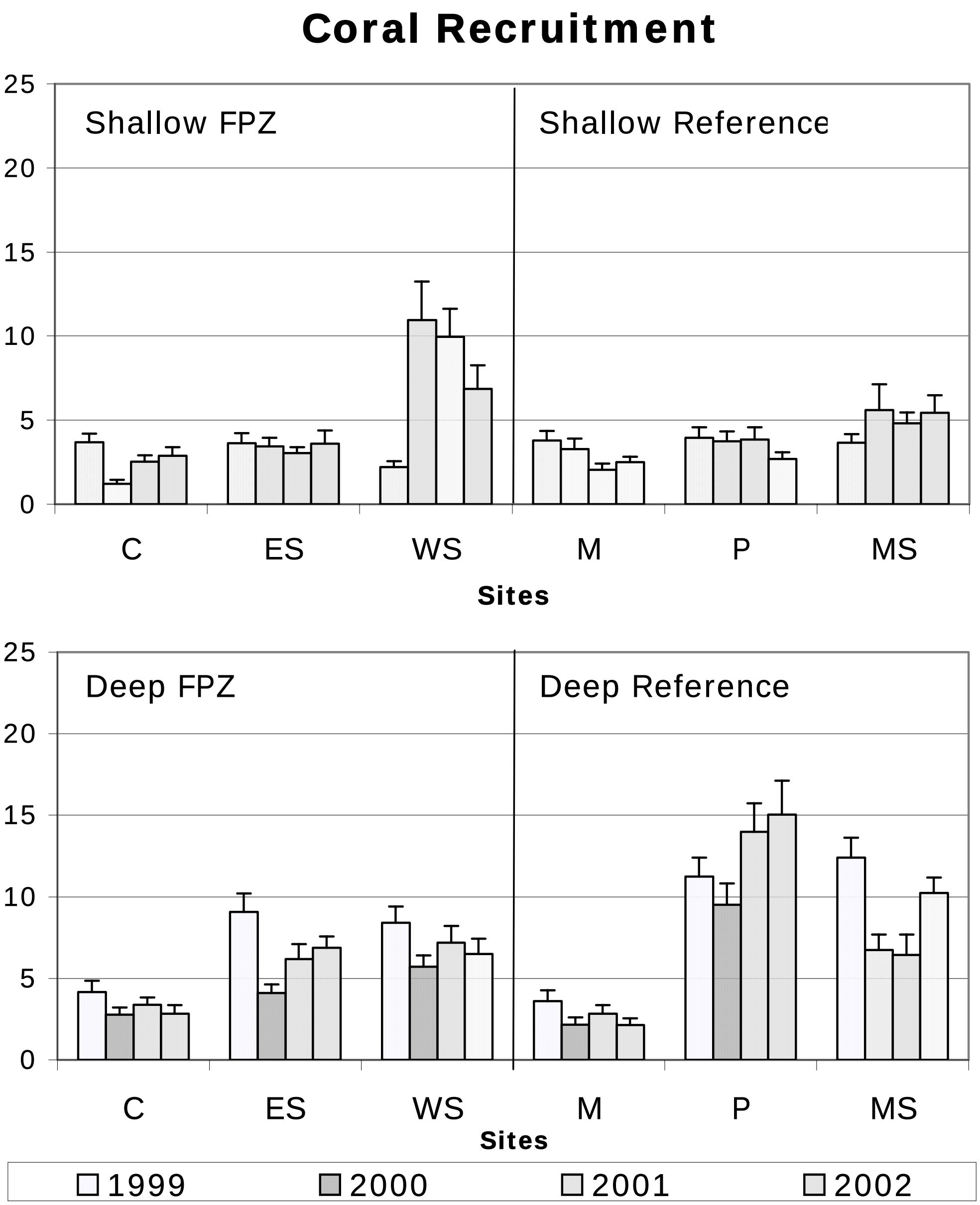


Figure 2. Patterns of juvenile coral recruitment in Fully Protected Marine Zones (FPZ) and adjacent reference areas from 1998 to 2003. Thirty-four permanent quadrats were censused visually on an annual basis at each depth at each site. C = Carysfort SPA, ES = Eastern Sambo ROA, WS = Western Sambo ER, M = Maitland, P = Pelican Shoal, MS = Middle Sambo. FPZ and reference pairs are C+M; ES+P; WS+MS. Error bars = 1 SE.

Keys. An ad hoc study was initiated in 2002 to begin to understand one aspect of the many that may influence coral recruitment. Settlement tile arrays were deployed at the deeper depths at the Carysfort SPA and Maitland reference sites and at the Eastern Sambo ROA and Middle Sambo reference sites in July 2002. The arrays will be retrieved in 2003 and all newly settled corals on the tiles identified. Differences in patterns of larval settlement may indicate differences in larval supply to the Upper and Lower Keys. A parallel project is being conducted simultaneously by NOAA scientists (Piniak, Fonseca, and Kenworthy) in the Tortugas. The combined data sets will give us an indication of possible gradients in coral larval settlement along the Florida Reef Tract.

Juvenile coral mortality patterns

Juvenile coral mortality rates are generally more consistent (20 to 40% per year) across sites and depths with little distinction between FPMZs and reference sites since 1999 (Fig. 3). Also, no distinctions appear between the Lower and Upper Keys sites. This might indicate that factors that contribute to juvenile coral mortality (sedimentation, algal overgrowth, and predation) are more uniformly distributed along the Florida Reef Tract than the factors that promote recruitment. However we lack any data with regard to these potential agents of coral mortality.

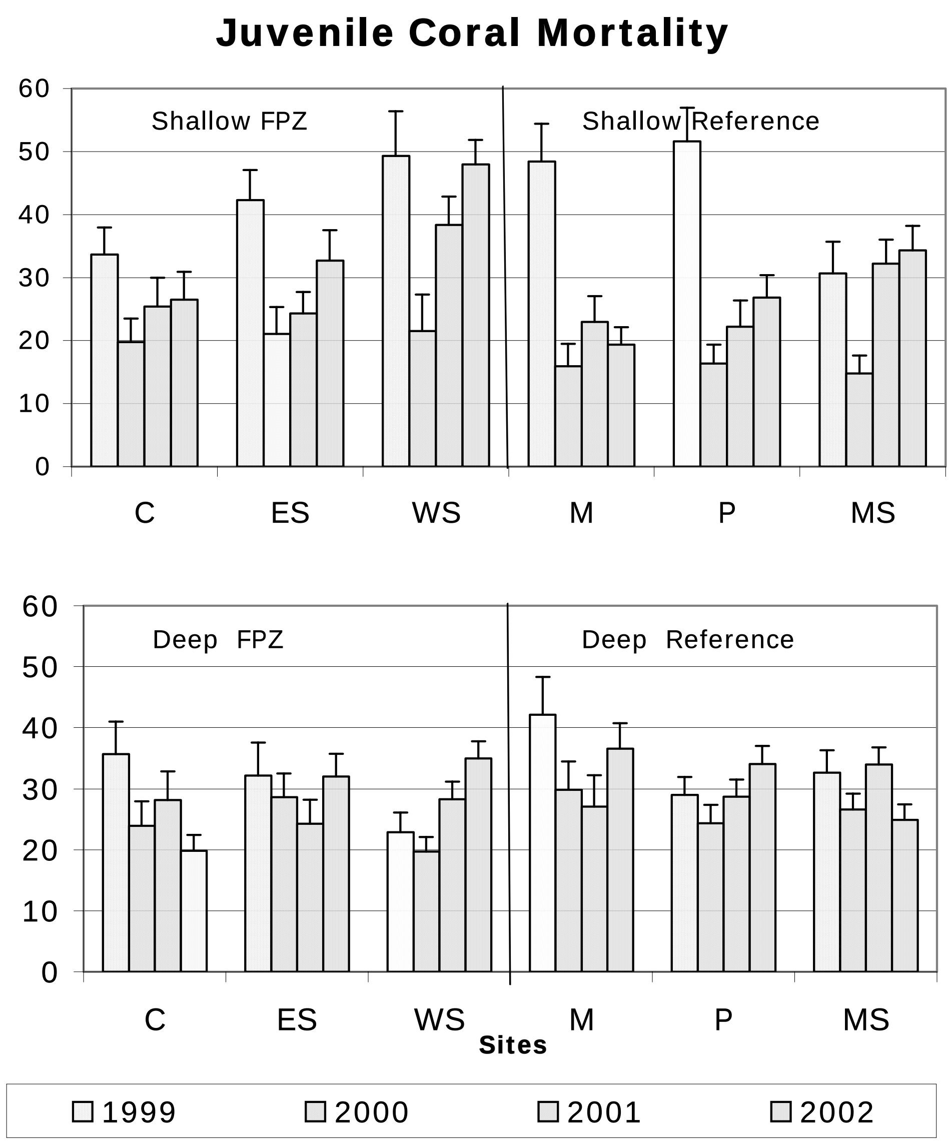


Figure 3. Patterns of juvenile coral mortality in Fully Protected Marine Zones (FPZ) and adjacent reference areas in the permanent quadrats from 1998 to 2003. Site labels as listed in Fig. 2. Error bars = 1 SE.

All the shallow sites, except for the Maitland reference site, have experienced increasing rates of mortality since 2000. Mortality rates at the Western Sambo ER shallow site were nearly 50% and there was a concomitant reduction in recruitment at this site. Correlation analyses of recruitment and mortality were performed by region and by depth, but no significant patterns existed between these data sets. The Western Sambo ER deep site has had consistent increases in mortality rates since 2000. All the other deep sites have had both increases and decreases in mortality since 1999.

Species-specific Patterns of Recruitment and Mortality

In general terms, both brooding corals (agariciids and poritids) and broadcast-spawning corals (*Siderastrea siderea* and *Montastraea cavernosa*) have recruited successfully since 1999 (Fig. 4). The 2002 data require follow-up surveys (i.e., in 2003) to confirm the initial species identifications. The older, larger colonies show species characteristics more clearly.

Very few of the massive framework-building species (*Diploria* spp., *Montastraea, "annularis,"* and *Colpophyllia natans*) have recruited successfully, if at all. Since 1998 we have only confirmed two new *Montastraea "annularis"* recruits in the original six sites (12 depth locations). The indications are that recruitment of these key species does occur, albeit widely dispersed in time and space, an inherent trait of these K-selected species. The fact that other broadcasting species (*Siderastrea siderea* and *Montastraea cavernosa*) are more successful indicates that water column processes (fertilization, predation, and hydrography) are not limiting factors. The sporadic success of some broadcasting species may be due to one or more factors such low population density (an Allee effect, in the case of *Colpophyllia* and *Diploria*), lack of recruitment cues, or species-specific post-settlement processes.

Patterns of mortality in the marked juvenile corals within the quadrats did not show strong differences between species, within years, or across depths (Fig. 5). Also, there do not appear to be differences in mortality rates between FPMZs and reference sites. The presented data for *Agaricia* spp. and *Montastraea cavernosa* show the high mortality in 1999 as a result of the effects of storm waves from Hurricanes Georges and Mitch in the fall of 1998. Mortality rates were reduced in subsequent years, but were not consistently low at all sites or depths. Once the 2002 data are fully processed the species-specific mortality data will be subjected to a nested ANOVA to test for treatment effects.

Adequacy of Sampling Effort

The aggregate quadrat area from the original 12 locations is 252 m^2, which may appear to be a trivial area with which to assess key processes along the Florida Reef Tract. However, the 2002 data brought the total number of unique corals observed in the study to just under 10,000 or approximately 25 colonies recruiting, growing, or dying in each of the 384 quadrats over the five annual periods. This level of data density does provide a robust picture of changes in juvenile coral populations. Data from the new study sites in the Upper Keys will provide a clearer picture of similarity or difference between the Upper and Lower Keys and between FPMZs and reference sites.

Acknowledgements
We are very appreciative of the support given to this project by Dr. Steven Miller and the excellent staff at the NURC lab in Key Largo. Paradise Divers in Ohio Key have worked long and hard to provide diving support for us in Key West. We thank Steve Baumgartner for providing FKNMS vessel support for us in Key West as well.

We could not do this work without our very dedicated teams of technicians and student interns and the logistical support provided by the staff at FIO.

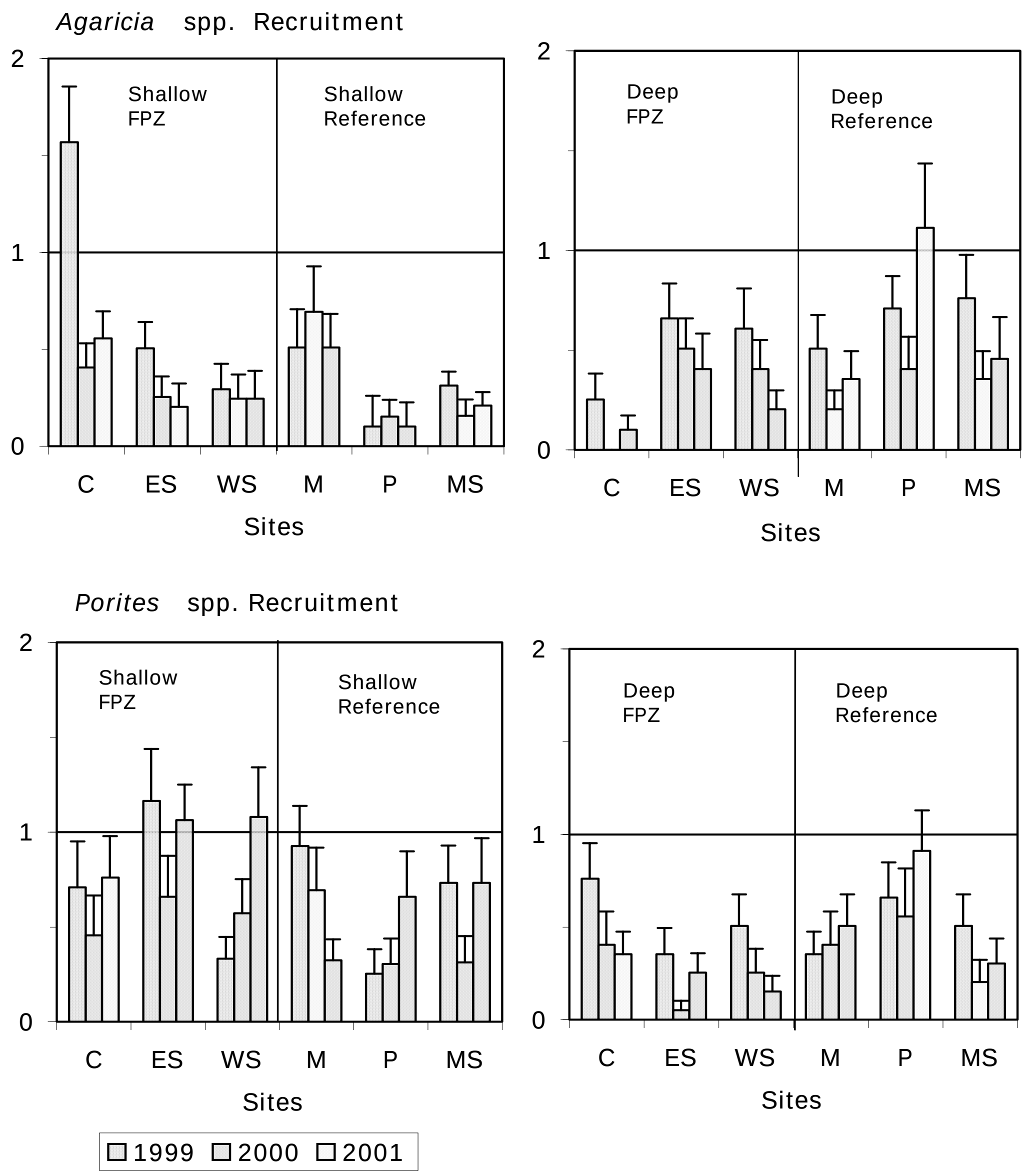


Figure 4. Patterns of recruitment by the dominant brooding corals in Fully Protected Marine Zones (FPZ) and adjacent reference areas. Site labels as listed in Fig. 2. Error bars = 1 SE.

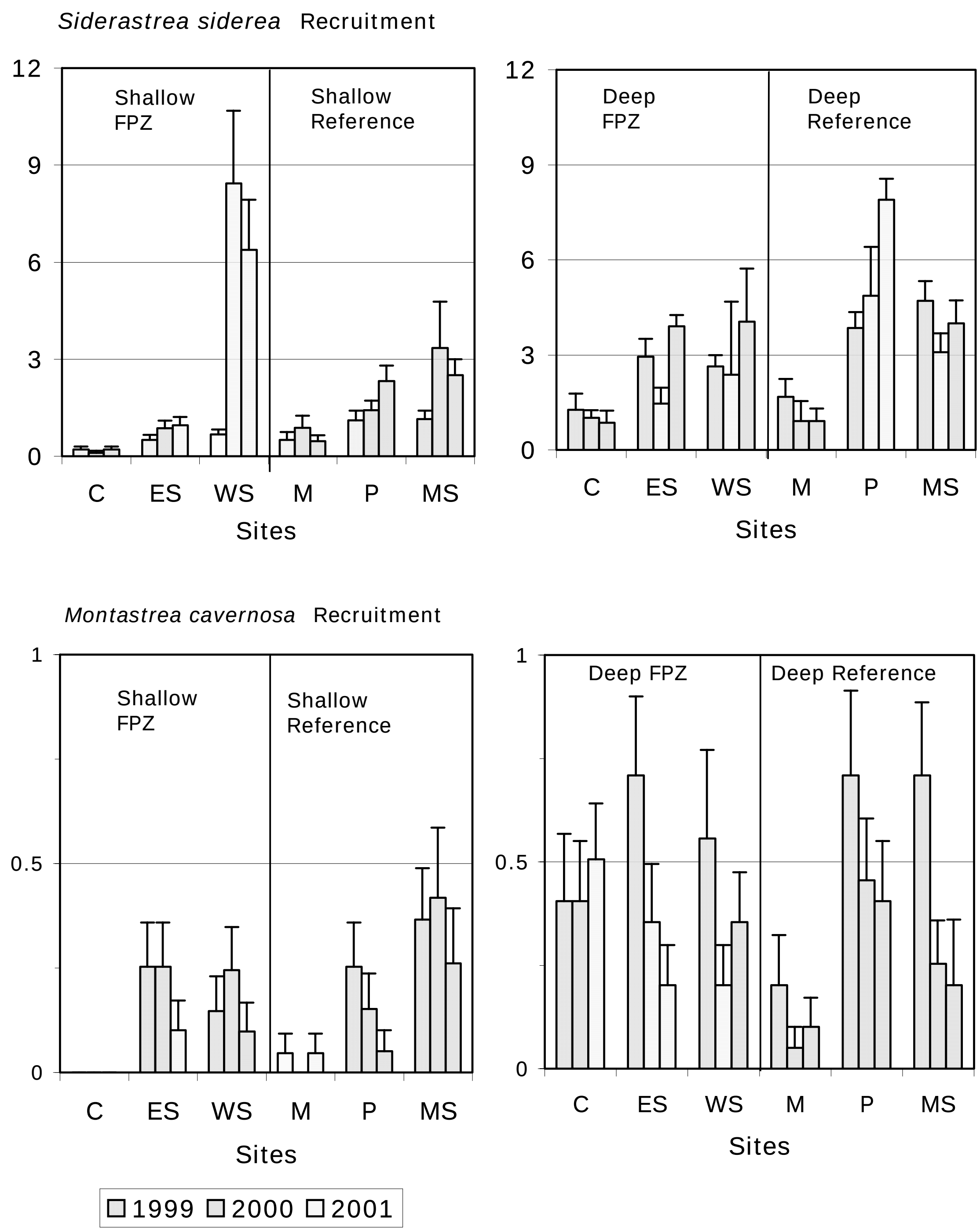


Figure 5. Patterns of recruitment by the dominant broadcasting corals in Fully Protected Marine Zones (FPZ) and adjacent reference areas. Site labels as listed in Fig. 2. Error bars = 1 SE. No *M. cavernosa* recruits have been observed in the quadrats at the Carysfort SPA shallow site.

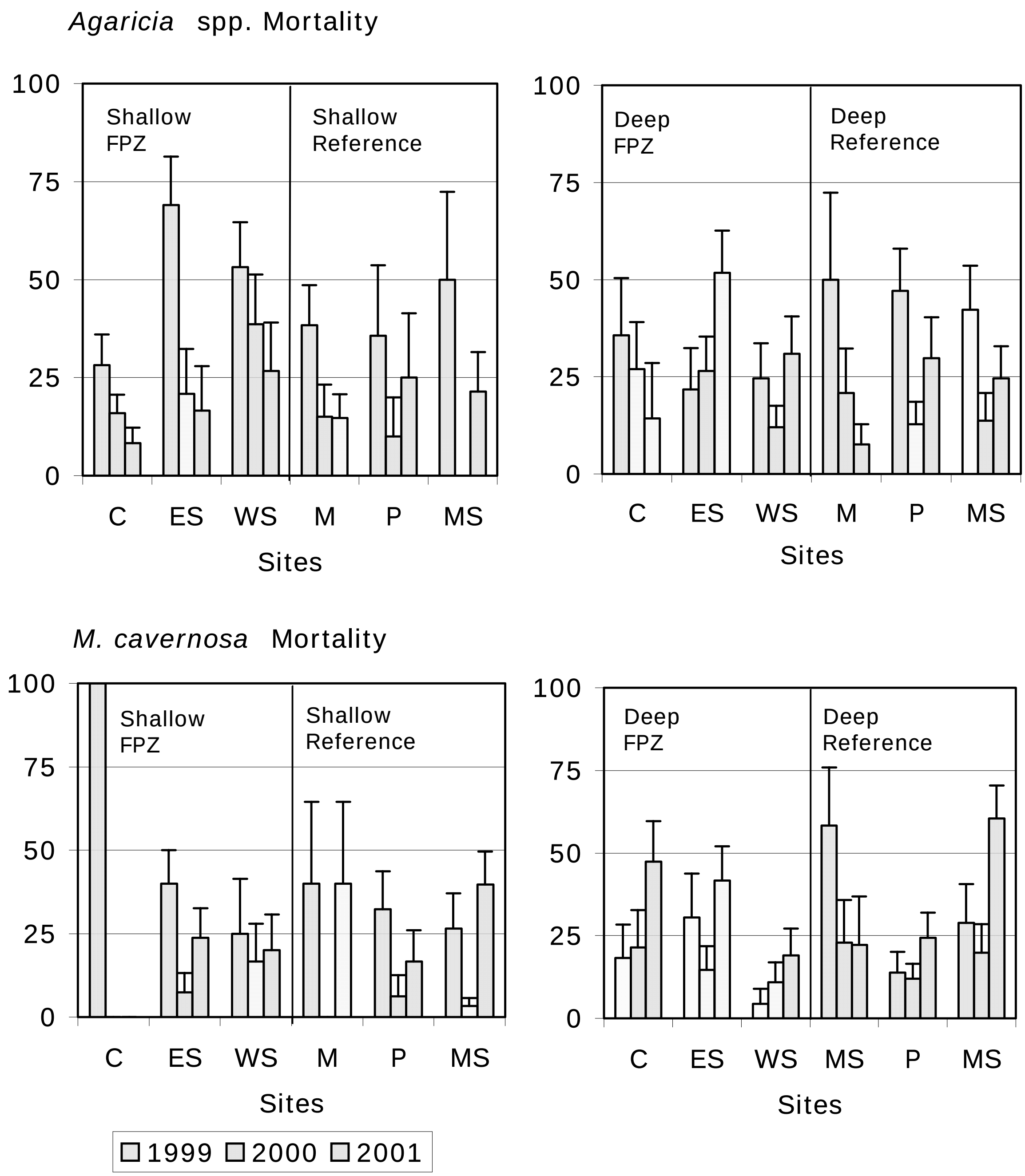


Figure 6. Patterns of mortality for juvenile colonies of two common corals in Fully Protected Marine Zones (FPZ) and adjacent reference areas. Site labels as listed in Fig. 2. Error bars = 1 SE. All *M. cavernosa* juvenile corals in the Carysfort SPA shallow site were killed off in 1998-99.

Rapid Assessment and Monitoring of Coral Reef Habitats on the Florida Reef Tract, Summer 2002

Steven L. Miller (Principal Investigator) and Mark Chiappone (Project Manager) (Center for Marine Science Research and NOAA's National Undersea Research Center [NURC], University of North Carolina at Wilmington [UNCW], Key Largo, FL)
Dione W. Swanson (Center for Marine Science Research, UNCW, Key Largo, FL and Division of Marine Biology and Fisheries, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL)
Mark Vermeij (Cooperative Institute for Marine and Atmospheric Studies, NOAA/NMFS, Southeast Fisheries Science Center, Miami, FL)
Dave Eaken (Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, South Florida Regional Laboratory, Marathon, FL)

Cooperating Institutions and Funding
Florida Keys National Marine Sanctuary, Emerson Associates International, Rosenstiel School of Marine and Atmospheric Science-University of Miami, NOAA's National Marine Fisheries Service, National Undersea Research Center at the University of North Carolina at Wilmington, and the State of Florida.

Sampling Goals and Objectives
The 2002 sampling of coral reef and hard-bottom habitats throughout the extent of the Florida Reef Tract, including the Biscayne Bay and Dry Tortugas regions, complemented a multi-year effort dating back to 1999 (with pilot studies conducted in 1998) to assess shallow-water (< 21 m) coral reef and hard-bottom habitat types in the Sanctuary, including most of the Sanctuary Fully Protected Marine Zones (FPMZs; Ecological Reserves, Sanctuary Preservation Areas [SPAs], and Research Only Areas [ROAs]) established in 1997 (23) and 2001 (Tortugas Ecological Reserve). The goals of the NURC/UNCW monitoring effort are three-fold:

- To assess community structure and condition of benthic communities at multiple spatial scales, with particular reference to the Sanctuary FPMZs. Variation is assessed among habitat types and among regions for particular habitat types.
- To assess potential changes in coral reef communities due to "no-take" protection from fishing within the Sanctuary FPMZs, as well as from changes caused by larger-scale factors, such as geography and water quality.
- To provide fishery-independent reef fish surveys (conducted at the same time as the benthic surveys) with detailed habitat information, to facilitate modeling efforts to evaluate essential fish habitat.

The 2002 Keys-wide cruise focused on the following tasks:

- To survey multiple coral reef and hard-bottom habitat types in the Biscayne Bay region of the Florida Reef Tract to complement surveys of similar habitat types in the Upper, Middle, and Lower Keys during 1999-2001.
- To survey multiple coral reef and hard-bottom habitat types in the Dry Tortugas to complement surveys of similar habitat types in the Dry Tortugas during 1999-2000.

- To survey deeper (15-21-m depth) low-relief spur and groove and low-relief hard-bottom habitats throughout the Florida Reef Tract to provide a temporal comparison to similar surveys conducted during 1995 from Biscayne Bay to the Dry Tortugas.

Logistics and Methods

A two-stage stratified random sampling design was used to select sites during 2002. A grid system constructed in a geographic information system (GIS) was used to overlay the existing habitat map of the Florida Keys. Sites or "blocks" 200 m x 200 m in dimension were used to randomly select sites from the following regional and habitat strata (Table 1):

- Biscayne Bay region: offshore patch reef, low-relief hard-bottom, and low-relief spur and groove
- Upper to Lower Keys: offshore patch reef, low-relief hard-bottom, and low-relief spur and groove
- Marquesas Keys: medium-profile reefs
- Dry Tortugas National Park: multiple reef and hard-bottom habitats
- Tortugas Bank: deep reef terraces

The 2002 effort included 14 sites east of Biscayne Bay (Fig. 1), 24 sites from Key Largo to Key West (Fig. 2 and 3), two sites south of the Marquesas Keys (Fig. 3), and 24 sites in the Tortugas region (Fig. 4). The 2002 sampling primarily focused on low-relief spur and groove and low relief hard-bottom at 15-21-m depth (Table 2). These two habitat types were sampled during a similar Keys-wide expedition during 1995, and the 2002 surveys were designed to provide a temporal comparison to this earlier study. Three of the low-relief spur and groove sites sampled from Key Largo to Key West were located within FPMZs: Carysfort Reef SPA, Conch Reef ROA, and Western Sambo Ecological Reserve (Table 2). Because many of the Sanctuary FPMZs do not extend beyond 12-m depth, low-relief spur and groove reefs were selected seaward of zone boundaries near 10 FPMZs: Elbow Reef, French Reef, Molasses Reef, Davis Reef, Alligator Reef, Tennessee Reef, Eastern Sambo, Eastern Dry Rocks, Rock Key, and Sand Key. One site or block was assigned to each zone and a total of 64 sites were surveyed between May 30 and June 30 (Table 2).

The 2002 sampling effort (64 sites) required 26 field days underwater from May 30 to June 30. Four days were lost to bad weather or other logistical issues. All 26 days were supported by NURC/UNCW extended operations aboard the M/V *Spree*. The field effort required approximately three or four dives a day by three to four divers. The 2002 sampling involved NURC/UNCW staff surveying the benthos, complemented by concurrent surveys of reef fishes by scientists from RSMAS-UM and NOAA/NMFS and lobster surveys by scientists from FWC/FWRI. Table 3 summarizes the diving statistics for this year. Over 360 hours of surveys by NURC/UNCW and reef fish surveyors were required to complete the sampling.

The 2002 surveys addressed the same variables measured during 1999-2001, in addition to several variables added to the existing design during 2001 (Table 4). Briefly, pre-determined GPS points were used to locate the survey site or block. Four independent, 15-m transects were deployed in each block, labeled in a numbered series from 1 to 4. The length of the transect was reduced from 25 m used in previous years because we optimized our sampling effort based on a statistical review of the existing data. Benthic coverage was estimated on all four transects and

Table 1. Sampling effort by habitat type and region in the Florida Keys during May-June 2002. The survey effort included 27 sites in Biscayne National Park (BNP) and Dry Tortugas National Park (DTNP), three sites within Sanctuary Fully Protected Marine Zones (FPMZs), and 10 sites just seaward of FPMZs.

Habitat type	Regional sector	Management type	No. of sites	Effort (%)
Offshore patch reef	Biscayne	Reference areas	2	3.1
	Lower Keys	Reference areas	2	3.1
Patch reef (Staghorn mound)	Dry Tortugas	DTNP	2	3.1
Reef knoll	Dry Tortugas	DTNP	3	4.7
High-relief spur and groove	Dry Tortugas	DTNP	1	1.6
Medium profile	Dry Tortugas	Reference areas	3	4.7
	Dry Tortugas	DTNP	1	1.6
Patchy hard-bottom in sand	Biscayne	BNP	2	3.1
Low-relief hard-bottom	Biscayne	BNP	6	9.4
	Upper Keys	Reference areas	2	3.1
	Upper Keys	FPMZs	1	1.6
	Dry Tortugas	Reference areas	4	6.3
	Dry Tortugas	DTNP	5	7.8
Low-relief spur and groove	Biscayne	BNP	4	6.3
	Upper Keys	Reference areas	5	7.8
	Upper Keys	FPMZs	1	1.6
	Middle Keys	Reference areas	4	6.3
	Middle Keys	FPMZs	1	1.6
	Lower Keys	Reference areas	7	10.9
	Lower Keys	FPMZs	1	1.6
Low-relief spur and groove	Dry Tortugas	DTNP	1	1.6
Reef terrace	Dry Tortugas	DTNP	1	1.6
	Dry Tortugas	Tortugas North ER	4	6.3
Seagrass matrix	Dry Tortugas	DTNP	1	1.6
Total			64	100.0

was determined every 15 cm to yield 100 points per transect. The number of species of stony corals, gorgonians, and sponges were determined on all four transects within a 0.5-m swath on either side of a 15-m transect (total survey area = 15 m^2 per transect). Gorgonian density was determined along two of the four transects within a 0.5-m swath on either side of the transect to the 8-m mark (total survey area = 8 m^2 per transect). Coral density, size, and condition were also determined along two of the four transects with the length of each swath fixed at 10 m (total survey area = 10 m^2 per transect). The coral condition measurements included identification of bleaching, disease, and an assessment of the extent to which interactions of coral and other taxa caused tissue damage or mortality. Juvenile corals (< 4 cm maximum diameter) were assessed along two of the four transects by randomly sampling 10 0.68-m x 0.45-m quadrats along each transect (total survey area = 3.12 m^2 per transect). Urchin density and test diameter, as well as the density of incidental marine invertebrates were assessed on all four transects at selected sites. Topographic complexity was measured along the four transects to describe bottom slope, maximum vertical relief, and the coverage of different relief categories along 1.0-m x 15-m swaths.

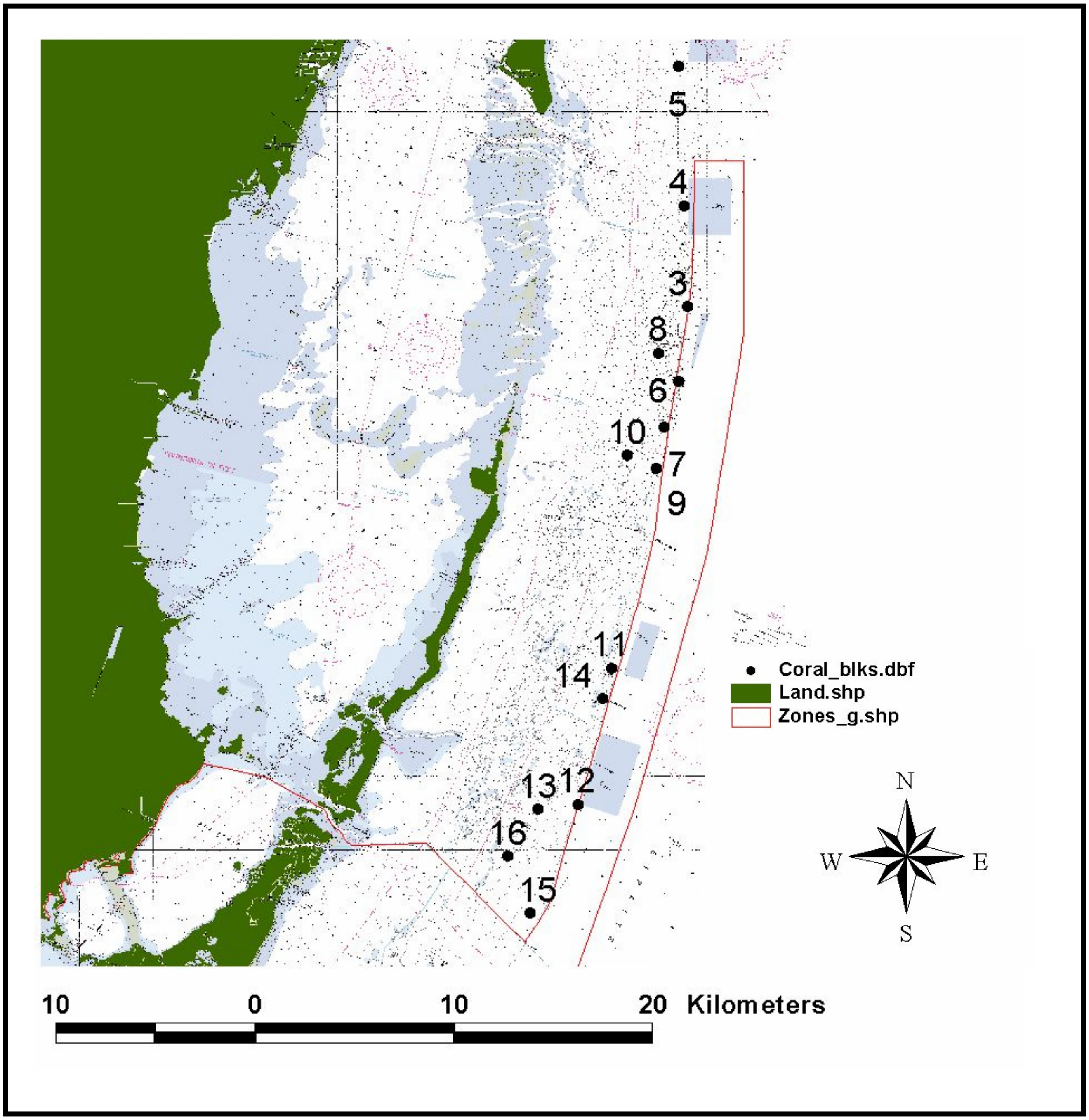


Figure 1. Survey locations in the Biscayne Bay area during 2002.

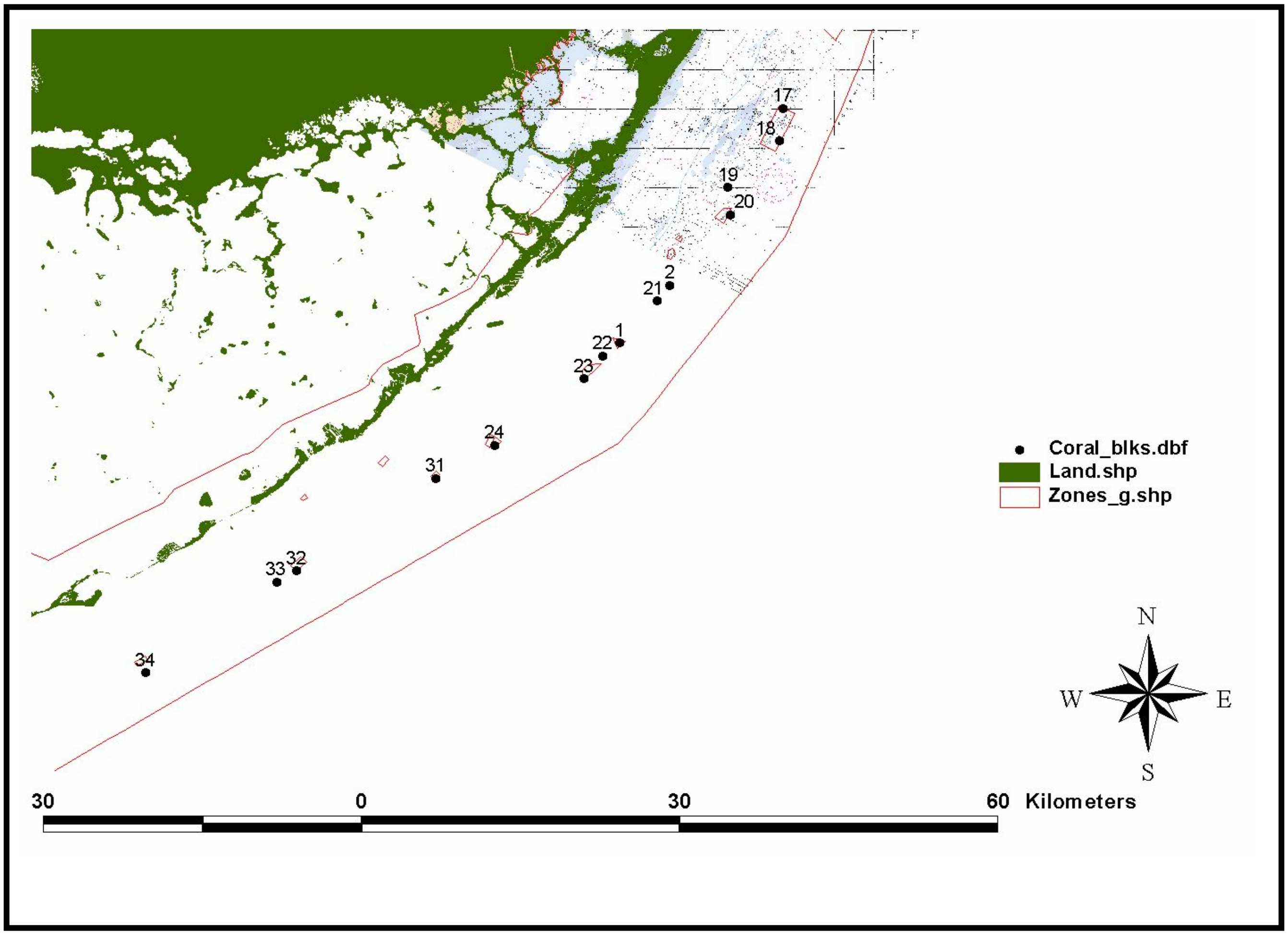


Figure 2. Survey locations in the upper and middle Florida Keys regions during 2002.

Summary of Results

The summary results presented below describe the principal variables measured during 2002 and focus on regional differences in the low-relief spur and groove habitat type from the Biscayne Bay region to the Tortugas. This latter discussion will be the focus of a paper comparing the recent Keys-wide survey with a similar study conducted in 1995.

Benthic Cover

Mean percent coverage data for scleractinian corals, fire coral (*Millepora* spp.), sponges, macroalgae, and algal turf are presented in Table 5. Patterns in coverage exhibited differences among the habitat types and broad regions surveyed. Overall, survey locations within the Biscayne region, across most of the habitat types, exhibited the lowest coral cover of the sites surveyed during 2002. Similar to earlier expeditions, offshore patch reefs exhibited some of the highest coral cover in the Biscayne and Florida Keys regions, ranging from 4% to nearly 28%. High-relief spur and groove (Bird Key Reef) and reef terrace habitats exhibited the highest coral cover in the Tortugas region and reef terraces exhibited the highest coral cover among all sites surveyed in 2002, ranging from 12% to 51%.

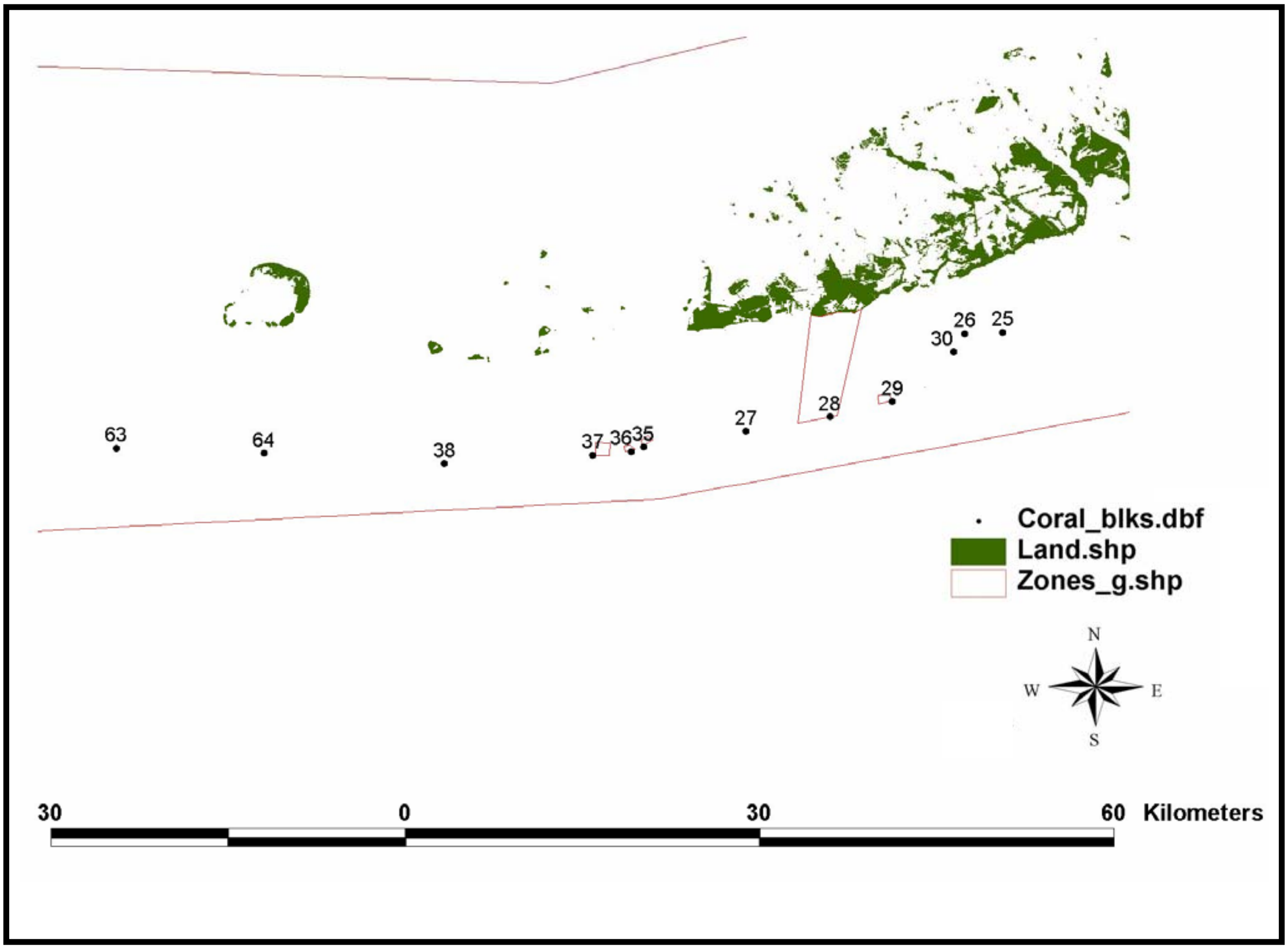


Figure 3. Survey locations in the lower Florida Keys and Marquesas Keys areas during 2002.

Offshore sampling locations in the Biscayne region and the Keys included three habitat types: low-relief spur and groove, low relief hard-bottom, and patchy hard-bottom in sand. Not unexpectedly, coral cover offshore was greatest on low-relief spur and groove reefs, ranging from about 1% to nearly 15%. Surprisingly, coral cover did not tend to be greater within Fully Protected Marine Zones (FPMZs). This contrasts with 2001 surveys of high-relief spur and groove reefs, in which sites within FPMZs tended to have greater coral cover than adjacent reference sites. These results point to the value of sampling multiple habitat types, which often vary significantly even within the boundaries of individual Sanctuary FPMZs.

Sampling locations in the Dry Tortugas region included patch reefs or dead *Acropora cervicornis* mounds, low-relief hard-bottom, low-relief spur and groove, medium-profile reefs, high-relief spur and groove, reef knolls, and reef terraces. Reef terraces on the Tortugas Bank and on the western rim of Dry Tortugas National Park had the greatest coral cover measured among all habitat types during 2002. Algal cover in this habitat type was composed largely of brown foliose algae, especially *Lobophora variegata*.

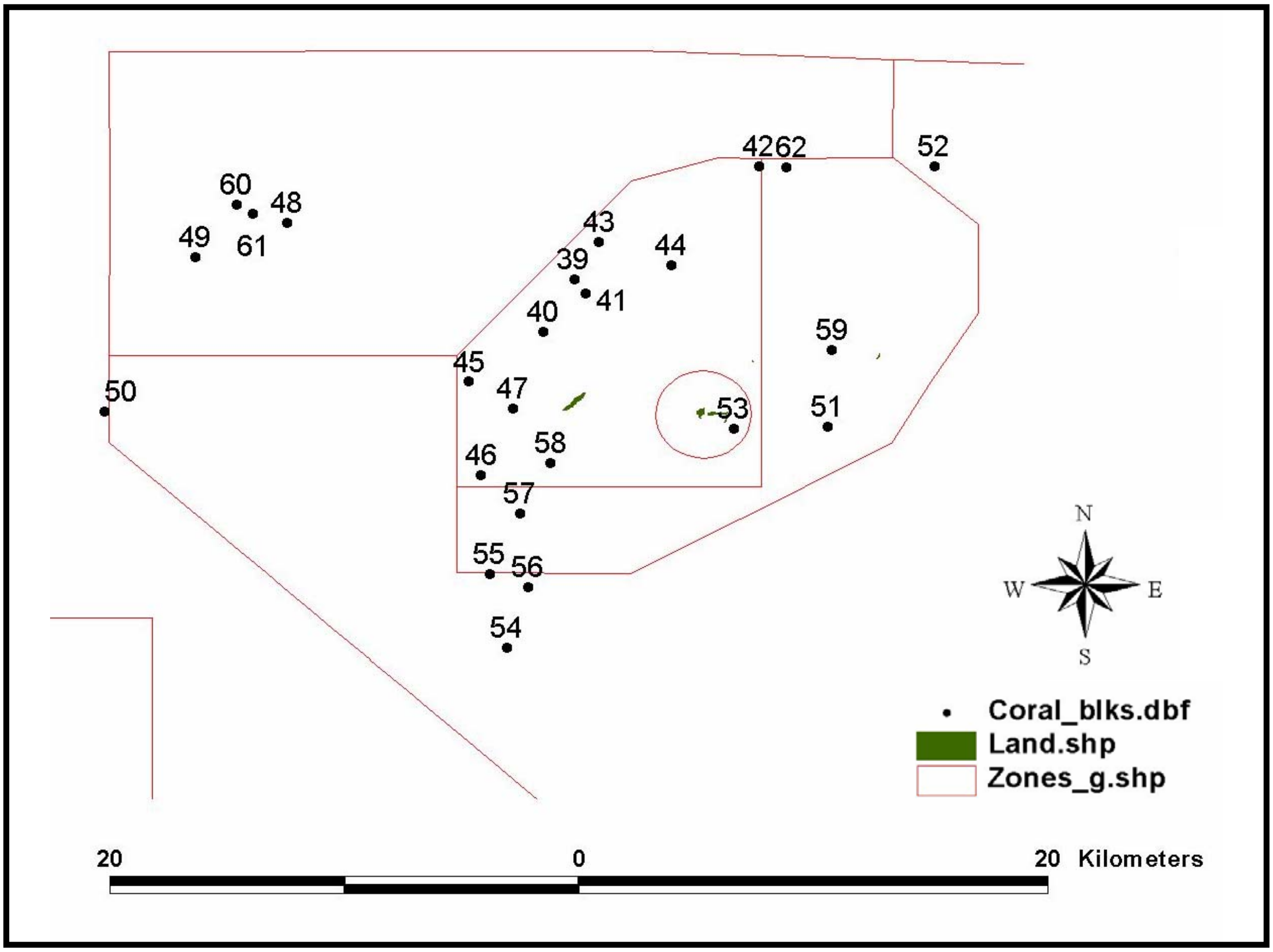


Figure 4. Survey locations in the Tortugas region during 2002.

Among the four regions surveyed in low-relief spur and groove habitat, coral cover was greatest in the Dry Tortugas (one site, 20.3%), followed by the Middle Keys (mean of 7.4% among five sites), the Lower Keys (6.8%), and the Upper Keys (3%), the latter including sites east of Biscayne Bay. While coral cover varied the most among sites in the Middle Keys (3.7% to 14.6%), we did not expect greater coral cover in this region relative to previous surveys in 1995. In fact, the pattern on deeper spur and groove reefs is opposite to that observed for shallower spur and groove reefs surveyed during 2001, in which reefs in the Upper and Lower Keys yielded the greatest coral cover. These results provide further support for broad geographic sampling across multiple habitat types and depths.

Species Richness

Surveys of the number of species of stony corals, gorgonians, and sponges continued during the 2002 surveys. Table 6 lists the coral, gorgonian, and sponge species surveyed from all sites during 2002. A total of 46 coral species, 33 gorgonians, and 80 sponge species were found. The total numbers of species surveyed by site for these three invertebrate groups are summarized by habitat and region in Table 7. Similar to results from 2000 and 2001, patch reefs in the Keys and

Table 2. Survey locations along the Florida Reef Tract during May-June 2002. Sites are arranged from northeast to southwest within each habitat type. Sites within Sanctuary FPMZs are noted with a single asterisk (*) and those adjacent to and seaward of zone boundaries are double asterisked (**).

Habitat type/site location	Region	Latitude	Longitude	Depth (m)
Offshore patch reef				
Inshore and SW of Pacific Reef	Biscayne	25.19.817	80.10.385	8.23-10.36
Inshore of Pacific Reef	Biscayne	25.21.095	80.09.551	10.06-10.97
West of W. Washerwoman Shoal	Lower Keys	24.32.579	80.36.076	5.18-7.01
West Washerwoman Shoal	Lower Keys	24.32.637	81.34.341	6.10-7.62
Patch reef (Staghorn mound)				
Dry Tortugas National Park	DTNP	24.36.537	82.55.831	9.45-10.36
Dry Tortugas National Park	DTNP	24.37.798	82.56.704	7.62-8.23
Reef knoll				
Dry Tortugas National Park	DTNP	24.37.378	82.49.468	14.02-17.98
Dry Tortugas National Park	DTNP	24.38.408	82.57.709	22.25-23.77
Dry Tortugas National Park	DTNP	24.41.616	82.54.714	10.97-11.89
High-relief spur and groove				
Bird Key Reef	Park	24.37.319	82.51.627	11.89-14.63
Medium-profile reef				
Coal Bin (East of Cosgrove Shoal)	Marquesas	24.27.014	82.08.089	16.76-17.37
Cosgrove Shoal	Marquesas	24.27.338	82.14.830	19.81-21.94
Pulaski Shoal (just outside DTNP)	Reference	24.43.367	82.47.006	17.07-17.37
Dry Tortugas National Park	DTNP	24.43.365	82.51.045	19.51-20.12
Patchy hard-bottom in sand				
Between Star & Triumph Reef	Biscayne	25.30.668	80.07.149	7.32-7.62
North of Fowey Rocks	Biscayne	25.37.442	80.05.600	10.67-11.58
Low-relief hard-bottom				
SW of Pacific Reef	Biscayne	25.18.272	80.09.772	11.89-11.89
Ajax Reef	Biscayne	25.24.093	80.07.796	6.10-7.32
North of Ajax Reef	Biscayne	25.24.914	80.07.580	7.01-8.84
Star Reef	Biscayne	25.31.448	80.06.142	11.28-12.19
Ledberry Reef	Biscayne	25.32.671	80.05.744	14.63-15.24
East of Biscayne Bay	Biscayne	25.41.200	80.05.746	8.84-10.36
Carysfort Reef*	Upper Keys	25.14.015	80.12.594	7.62-7.92
Seaward of Watson's Reef	Upper Keys	25.09.985	80.15.375	10.36-10.97
Between Molasses & French Reef	Upper Keys	25.01.438	80.21.732	10.97-11.89
S. DTNP (just outside park)	Reference	24.32.294	82.56.846	17.37-17.37
Dry Tortugas National Park	DTNP	24.33.690	82.56.353	14.33-14.94
Dry Tortugas National Park	DTNP	24.33.982	82.57.235	15.85-17.37
Dry Tortugas National Park	DTNP	24.35.383	82.56.541	12.80-13.72
Dry Tortugas National Park	DTNP	24.36.272	82.57.437	13.11-14.02
Dry Tortugas National Park	DTNP	24.40.434	82.55.023	9.14-10.36
DTNP (NW of Loggerhead Key)	Reference	24.40.772	82.55.278	15.24-16.15
Dry Tortugas National Park	DTNP	24.41.076	82.53.059	10.06-11.28
Tortugas Bank	Tortugas Bank	24.37.725	83.06.100	22.56-23.16

Table 2. continued.

Habitat type/site location	Region	Latitude	Longitude	Depth (m)
Low-relief spur and groove				
Offshore Pacific Reef	Biscayne	25.21.226	80.08.489	15.85-17.68
Between Star and Triumph Reef	Biscayne	25.30.334	80.06.348	10.97-12.50
SW of Brewster Reef	Biscayne	25.33.441	80.06.304	5.18-6.10
South of Fowey Rocks	Biscayne	25.34.699	80.05.519	15.54-19.20
Carysfort Reef SPA*	Upper Keys	25.12.371	80.12.780	16.76-18.90
Elbow Reef SPA**	Upper Keys	25.08.615	80.15.251	16.15-17.07
North Dixie Shoal	Upper Keys	25.05.032	80.18.337	14.63-16.46
Dixie Shoal	Upper Keys	25.04.232	80.18.995	14.63-15.85
French Reef**	Upper Keys	25.02.103	80.20.908	16.46-19.51
Molasses Reef**	Upper Keys	25.00.292	80.22.728	15.85-18.59
Conch Reef R-OA*	Middle Keys	24.56.903	80.27.250	14.33-15.54
Davis Reef**	Middle Keys	24.55.223	80.30.243	15.54-17.07
Alligator Reef**	Middle Keys	24.50.504	80.37.319	16.76-17.98
Between Tennessee & Alligator	Middle Keys	24.49.953	80.38.336	15.24-15.54
Offshore of Tennessee R-OA**	Middle Keys	24.45.331	80.45.021	15.24-16.76
East of Pelican Shoal	Lower Keys	24.30.274	81.36.000	11.89-13.41
Eastern Sambo**	Lower Keys	24.29.467	81.39.396	14.02-15.24
Western Sambo*	Lower Keys	24.28.771	81.42.240	14.94-15.85
Between W. Sambo & E. Dry Rocks	Lower Keys	24.28.113	81.46.068	17.37-18.59
Eastern Dry Rocks**	Lower Keys	24.27.386	81.50.750	15.54-17.68
Rock Key**	Lower Keys	24.27.188	81.51.320	13.41-16.15
Sand Key**	Lower Keys	24.27.025	81.53.069	14.63-15.85
SW of Western Dry Rocks	Lower Keys	24.26.636	81.59.849	14.93-16.46
Dry Tortugas National Park	DTNP	24.43.326	28.50.408	14.94-15.54
Reef terrace				
Loggerhead Forest	Park	24.39.558	82.56.005	16.46-17.37
Sherwood Forest	Tortugas Bank	24.41.274	83.04.010	23.16-23.77
Sherwood Forest	Tortugas Bank	24.42.052	83.01.899	24.99-26.21
Sherwood Forest	Tortugas Bank	24.42.275	83.02.671	21.64-22.25
Sherwood Forest	Tortugas Bank	24.42.469	83.03.055	23.77-24.38
Seagrass matrix community				
DTNP	Park	24.39.129	82.49.369	6.10-6.10

Biscayne regions typically yielded the greatest number of species of reef-building corals (Table 7). The number of sponges found on patch reefs in 2002 was similar or less than the number found on offshore forereef areas.

Overall, coral species numbers surveyed in the low-relief spur and groove habitat were highest in the Middle and Lower Keys. Fully Protected Marine Zones did not have significantly greater species numbers. Gorgonian species numbers were highest on patch reefs. On low-relief spur and groove reefs, gorgonian species richness was slightly higher in the Lower Keys. Sponge species numbers were similar throughout the region, among habitats, and between levels of protection. In the Dry Tortugas, coral species numbers were similar among all habitat types with low-relief hard-bottom at the low end of the range. Both gorgonian and sponge species numbers were lowest in reef terrace habitats, but similar among all other habitats.

Table 3. SCUBA diving effort in the Florida Keys during May-June 2002. Reef fish surveys reported are for dives conducted in conjunction with the benthic surveys.

Diver	Affiliation	No. of dives	Depth (ft.)	Bottom time (hrs.)
Benthic surveys				
Steven Miller	CMSR/UNCW	37	26-86	49.58
Mark Chiappone	CMSR/UNCW	21	19-66	23.48
Dione Swanson	CMSR/UNCW	60	17-86	75.53
Mark Vermeij	RSMAS/UM	55	10-85	67.5
Dave Eaken	FWC/FWRI	17	26-76	22.58
Subtotal		190	10-86	238.67
Reef fish surveys				
Steve Smith	RSMAS/UM	42	17-81	41.33
Mike Judge	NOAA/NMFS	21	30-79	21.67
Nicholas Farmer	RSMAS/UM	13	33-62	10.63
Mike Larkin	RSMAS/UM	22	28-65	17.77
Aaron Bartholomew	NOAA/NMFS	5	28-59	3.68
Lance Jordan	Nova Southeastern	12	22-70	11.58
Rob Waara	NPS/Virgin Islands	5	53-83	4.83
Brian Ettinger	Nova Southeastern	12	26-63	10.33
Subtotal		132	17-83	121.82
Total all divers		**322**	**10-86**	**360.49**

Table 4. Variables measured during 2002. Transects 15 m in length were used in all sites. Note that the width of the survey area along transects varied among variables.

Variable	Method	Factors assessed
Percent cover	Point-intercept along 4 transects (100 points/transect)	Percent cover
Species richness	1.0 m x 15 m swaths along 4 transects	Species presence & total number
Coral density and size	1.0 m x 10 m swaths along 2 transects	Density, size, condition
Juvenile coral density	Twenty 0.68 m x 0.45 m quadrats	Species composition, density & size
Gorgonian density	1.0 m x 8 m swaths along 2 transects	Density
Urchin density and size	1.0 m x 15 m swaths along 4 transects	Density, test diameter
Marine ornamentals	1.0 m x 15 m swaths along 4 transects	Density
Spiny lobster density	1.0 m x 15 m swaths along 4 transects	Density
Topography	1.0 m x 15 m swaths along 4 transects	Maximum relief & substratum slope

In the low-relief spur and groove habitat from east of Biscayne Bay to the lower Florida Keys, the mean number of coral species per site was greatest in the Middle Keys (22.2), followed by the Lower Keys (21.9) and the Upper Keys (16.9). This is similar to findings from shallower spur and groove reefs surveyed during 2001, in which the Upper Keys yielded the lowest species richness of corals. Similar to findings from 1999 and 2001, sponge species richness was, on average, greatest in the Middle Keys (39.6 species per site), compared to the Upper (37.8) and Lower Keys (35.9). Gorgonian species richness did not vary significantly among the three regions within this particular habitat type, ranging from an average of 14.9 to 16.9 species per site.

Table 5. Mean (1 SE) percent coverage of scleractinian corals, fire coral (*Millepora* spp.), sponges, macroalgae, and algal turf. Noted are sites within Sanctuary Fully Protected Marine Zones (FPMZs) (*) and those adjacent to and seaward of FPMZs (**). Data are based upon 100 points surveyed along each of four transects.

Habitat type/site location	Scleractinia	*Millepora*	Sponges	Macroalgae	Algal turf
Offshore patch reef					
Inshore and SW of Pacific Reef	3.8 (4.8)	1.3 (1.7)	0.3 (0.3)	35.9 (30.7)	21.2 (22.3)
Inshore of Pacific Reef	5.3 (6.6)	0.0 (0.0)	4.8 (6.0)	21.8 (22.7)	23.3 (23.8)
West Washerwoman Shoal	27.3 (26.4)	0.8 (1.0)	0.0 (0.0)	1.8 (2.3)	39.0 (31.7)
West of West Washerwoman	24.8 (24.8)	0.3 (0.3)	0.0 (0.0)	0.5 (0.7)	49.3 (33.3)
Patch reef (Staghorn mound)					
Dry Tortugas National Park	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	72.8 (26.4)	9.0 (10.9)
Dry Tortugas National Park	0.3 (0.3)	0.5 (0.7)	0.0 (0.0)	47.3 (33.2)	4.3 (5.4)
Reef knoll					
Dry Tortugas National Park	14.0 (24.1)	0.5 (1.0)	3.0 (5.8)	7.0 (13.0)	27.0 (39.4)
Dry Tortugas National Park	31.7 (32.5)	0.0 (0.0)	0.0 (0.0)	22.7 (26.3)	22.3 (26.0)
Dry Tortugas National Park	2.5 (3.2)	0.5 (0.7)	0.0 (0.0)	43.7 (32.8)	7.0 (8.7)
High-relief spur and groove					
Bird Key Reef	25.8 (25.5)	0.8 (1.0)	0.0 (0.0)	11.3 (13.3)	24.5 (24.7)
Medium-profile reef					
Coal Bin (East of Cosgrove Shoal)	5.0 (6.3)	0.0 (0.0)	0.0 (0.0)	56.5 (32.8)	21.3 (22.3)
Cosgrove Shoal	9.3 (11.2)	0.0 (0.0)	0.0 (0.0)	56.8 (32.7)	25.3 (25.2)
Dry Tortugas National Park	16.8 (18.6)	0.0 (0.0)	0.0 (0.0)	15.8 (17.7)	37.3 (31.2)
Pulaski Shoal	7.5 (13.9)	0.0 (0.0)	6.0 (11.3)	26.5 (39.0)	12.5 (21.9)
Patchy hard-bottom in sand					
Between Star & Triumph Reef	3.0 (3.9)	0.0 (0.0)	2.3 (2.9)	7.5 (9.3)	25.5 (25.3)
North of Fowey Rocks	0.0 (0.0)	0.8 (1.0)	0.3 (0.3)	6.3 (7.8)	49.3 (33.3)
Low-relief hard-bottom					
SW of Pacific Reef	0.8 (1.0)	0.5 (0.7)	0.5 (0.7)	21.3 (22.4)	50.7 (33.3)
Ajax Reef	1.5 (2.0)	0.5 (0.7)	3.8 (4.8)	34.8 (30.2)	37.8 (31.3)
North of Ajax Reef	0.8 (1.0)	0.0 (0.0)	2.0 (2.6)	30.8 (28.4)	45.0 (33.0)
Star Reef	0.5 (0.7)	0.3 (0.3)	0.8 (1.0)	21.5 (22.5)	48.5 (33.3)
Ledberry Reef	0.5 (0.7)	1.0 (1.3)	0.0 (0.0)	13.0 (15.1)	47.3 (33.2)
East of Biscayne Bay	2.0 (2.6)	0.5 (0.7)	0.8 (1.0)	8.5 (10.4)	53.5 (33.2)
Carysfort Reef*	2.5 (3.3)	0.5 (0.7)	1.2 (1.6)	36.0 (30.7)	34.1 (30.0)
Seaward of Watson's Reef	2.8 (3.6)	0.3 (0.3)	1.5 (2.0)	41.4 (32.4)	31.5 (28.8)
Between Molasses & French Reef	3.0 (3.9)	0.3 (0.3)	0.0 (0.0)	33.8 (29.8)	42.8 (32.6)
Southern DTNP (outside park)	2.5 (3.3)	0.3 (0.3)	0.0 (0.0)	42.0 (32.5)	12.0 (14.1)
Dry Tortugas National Park	3.3 (4.2)	0.5 (0.7)	0.0 (0.0)	42.3 (32.5)	13.3 (15.3)
Dry Tortugas National Park	3.5 (4.5)	0.3 (0.3)	0.0 (0.0)	44.0 (32.9)	17.5 (19.3)
Dry Tortugas National Park	4.0 (5.1)	1.3 (1.6)	0.5 (0.7)	35.0 (30.3)	37.8 (31.3)
Dry Tortugas National Park	8.3 (10.1)	1.3 (1.6)	0.0 (0.0)	33.8 (29.8)	6.0 (7.5)
Tortugas Bank	2.0 (2.6)	0.0 (0.0)	0.0 (0.0)	56.4 (32.8)	3.5 (4.5)
Dry Tortugas National Park	2.0 (2.6)	1.3 (1.6)	0.0 (0.0)	36.8 (31.0)	21.8 (22.7)
NW of Loggerhead Key	2.0 (2.6)	0.3 (0.3)	0.0 (0.0)	34.0 (29.9)	27.5 (26.6)
Dry Tortugas National Park	0.5 (0.7)	0.0 (0.0)	0.0 (0.0)	42.5 (32.6)	14.3 (16.3)

Table 5. continued.

Habitat type/site location	Scleractinia	*Millepora*	Sponges	Macroalgae	Algal turf
Low-relief spur and groove					
Offshore Pacific Reef	1.0 (1.3)	1.8 (2.3)	0.3 (0.3)	7.5 (9.3)	29.5 (27.7)
Between Star & Triumph Reef	2.5 (3.3)	0.0 (0.0)	1.5 (2.0)	32.3 (29.1)	35.8 (30.6)
SW of Brewster Reef	4.3 (5.4)	1.0 (1.3)	1.3 (1.6)	11.3 (13.3)	35.3 (30.4)
South of Fowey Rocks	3.2 (4.2)	0.6 (0.9)	0.6 (0.9)	21.0 (22.1)	28.5 (27.2)
Carysfort Reef SPA*	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	24.3 (24.5)	60.5 (31.9)
Elbow Reef SPA**	1.7 (2.3)	0.3 (0.3)	0.0 (0.0)	39.3 (31.8)	28.1 (26.9)
North Dixie Shoal	2.3 (2.9)	0.8 (1.0)	1.3 (1.6)	54.0 (33.1)	4.8 (6.0)
Dixie Shoal	6.5 (8.1)	0.5 (0.7)	0.0 (0.0)	49.1 (33.3)	26.2 (25.8)
French Reef**	4.0 (5.8)	0.3 (0.5)	0.3 (0.5)	51.7 (37.5)	10.3 (13.9)
Molasses Reef**	3.8 (4.8)	0.3 (0.3)	0.0 (0.0)	46.5 (33.2)	25.0 (25.0)
Conch Reef RO*	4.5 (5.7)	0.8 (1.0)	0.0 (0.0)	42.8 (32.6)	13.5 (15.6)
Davis Reef**	4.0 (5.1)	0.3 (0.3)	0.0 (0.0)	46.5 (33.2)	28.8 (27.3)
Alligator Reef**	3.7 (4.8)	1.7 (2.3)	0.0 (0.0)	19.6 (21.0)	20.3 (21.6)
Between Tennessee & Alligator	14.7 (16.7)	0.7 (1.0)	0.0 (0.0)	35.6 (30.6)	34.3 (30.0)
Offshore of Tennessee RO**	10.3 (12.3)	0.0 (0.0)	0.0 (0.0)	41.5 (32.4)	38.0 (31.4)
East of Pelican Shoal	0.8 (1.0)	1.0 (1.3)	0.0 (0.0)	37.2 (31.1)	16.2 (18.1)
Eastern Sambo Reef**	7.8 (9.5)	0.0 (0.0)	0.0 (0.0)	39.0 (31.7)	21.0 (22.1)
Western Sambo Reef*	10.3 (12.3)	0.0 (0.0)	0.0 (0.0)	42.0 (32.5)	19.8 (21.1)
Between W. Sambo & E. Dry Rocks	13.3 (15.3)	0.3 (0.3)	0.0 (0.0)	50.0 (33.3)	11.0 (13.1)
Eastern Dry Rocks**	7.5 (9.3)	0.5 (0.7)	0.0 (0.0)	45.8 (33.1)	38.0 (31.4)
Rock Key**	6.5 (8.1)	0.3 (0.3)	0.0 (0.0)	34.8 (30.2)	51.0 (33.3)
Sand Key**	3.3 (4.2)	0.0 (0.0)	0.0 (0.0)	63.0 (31.1)	27.3 (26.4)
SW of Western Dry Rocks	4.8 (6.0)	0.5 (0.7)	0.0 (0.0)	45.3 (33.0)	37.5 (31.3)
Dry Tortugas National Park	20.3 (21.5)	1.3 (1.6)	0.0 (0.0)	38.0 (31.4)	24.8 (24.8)
Reef terrace					
Loggerhead Forest	50.5 (33.3)	0.8 (1.0)	0.0 (0.0)	27.5 (26.6)	10.3 (12.3)
Sherwood Forest	29.8 (27.9)	0.3 (0.3)	0.0 (0.0)	35.0 (30.1)	0.5 (0.7)
Sherwood Forest	32.7 (33.0)	0.0 (0.0)	0.0 (0.0)	32.9 (33.1)	0.5 (0.8)
Sherwood Forest	24.0 (24.3)	0.0 (0.0)	0.0 (0.0)	41.3 (32.3)	10.0 (12.0)
Sherwood Forest	11.5 (13.6)	0.3 (0.3)	0.0 (0.0)	56.9 (32.7)	12.5 (14.6)

Coral Density, Size, and Condition

Coral density, size, and condition measurements were made using methods similar to previous years. Table 8 lists the density of scleractinian corals by site. The total area surveyed during 2002 was approximately 1,280 m^2. Over 7,250 corals were counted and measured from the 64 sites, of which 2,098 or 29% were fire coral (*Millepora alcicornis*) and 5,161 or 71% were scleractinian corals.

Although scleractinian coral densities are highly variable, there were some patterns. In the broad Biscayne and Keys area, scleractinian corals exhibited differences in density among habitat types and regional sectors. Coral density was highest on offshore patch reefs in the Lower Keys. Densities were relatively similar among all other habitats in the Lower, Middle, and Upper Keys, while density values in the Biscayne region were lower than the Keys for all habitat types sampled. In the Dry Tortugas, the highest coral densities were found on reef terraces, reef knolls, high-relief spur and groove (Bird Key Reef), and low-relief spur and groove. Within the low-relief spur and groove habitat, mean coral densities within particular regions were greatest in the Dry Tortugas (one site, 9.55 colonies/m^2), followed by the Middle Keys (5.49 colonies/m^2). Size and condition data were not analyzed for this report.

Table 6. Coral, gorgonian, and sponge species surveyed during May-June 2002. Listed are only those species recorded within four 15-m^2 plots per site.

Stony corals	Gorgonians	Sponges	
Acropora cervicornis	*Briareum asbestinum*	*Adocia sp.*	*Pandaros acanthifolium*
Agaricia agaricites	*Erythrop. caribaeorum*	*A. carbonifera*	*Pseudoaxinella lunaecharta*
A. fragilis	*Eunicea calyculata*	**Agelas clathrodes**	*Pseudoceratina crassa*
A. grahamae	*E. fusca*	*A. conifera*	*Ptilocaulis* sp.
A. humilis	*E. laciniata*	*A. schmidti*	*Rhaphidophlus juniperinis*
A. lamarcki	*E. mammosa*	*A. wiedenmayaari*	*R. venosus*
Colpophyllia natans	*E. palmeri*	*Amphimedon compressa*	*Siphon. coralliphagum*
Dichocoenia stokesi	*E. succinea*	*A. viridis*	*S. siphonum*
Diploria clivosa	*E. tourneforti*	*Anthosigmella varians*	*Spheciospongia vesparium*
D. labyrinthiformis	*Gorgonia ventalina*	*Aplysina archeri*	*Spinosella tenerrima*
D. strigosa	*Iciliogorgia schrammi*	*A. cauliformis*	*Spirastrella coccinea*
Eusmilia fastigiata	*Muricea atlantica*	*A. fistularis*	*Spongia* sp.
Favia fragum	*M. elongata*	*A. fulva*	*Strongylacidon* sp.
Isophyllastrea rigida	*M. muricata*	*A. lacunosa*	*Tedania ignis*
Isophyllia sinuosa	*M. pinnata*	*Callyspongia plicifera*	*Tethya crypta*
Leptoseris cucullata	*Muriceopsis flavida*	*C. vaginalis*	*Ulosa ruetzleri*
Madracis carmabi	*Plexaura flexuosa*	*Chondrilla nucula*	Unknown blue tube #1
M. decactis	*P. homomalla*	*Cinachyra* sp.	Unknown blue tube #2
M. formosa	*Plexaurella dichotoma*	*Clathria* sp.	Unknown brown *Cliona*
M. mirabilis	*P. grisea*	*Clathrina canariensis*	Unknown brown encrusting
M. senaria	*P. nutans*	*Cliona* sp.	Unknown brown lumpy
Manicina areolata	*P. pumila*	*C. deletrix*	Unknown brown smooth
Meandrina meandrites	*Pseudoplexaura crucis*	*C. langae*	Unknown brown tube
Millepora alcicornis	*P. flagellosa*	*Cribochalina vasculum*	Unknown carmine red
M. complanata	*P. porosa*	*Diplastrella megastellata*	Unknown encrusting
Montastraea annularis	*P. wagenaari*	*Dysidea etheria*	Unknown mauve lumpy
M. cavernosa	*Pseudopt. acerosa*	*Ectyoplasia ferox*	Unknown orange encrusting
M. faveolata	*P. americana*	*Erylus formosus*	Unknown red encrusting
M. franksi	*P. bipinnata*	*Geodia neptuna*	Unknown red lumpy
Mussa angulosa	*P. rigida*	*Haliclona hogarthi*	Unknown red squishy
Mycetophyllia aliciae	*Pterogorgia anceps*	*Halisarca* sp.	*Verongula gigantea*
M. danaana	*P. citrina*	*Holapsamma helwigi*	*V. rigida*
M. ferox	*P. guadalupensis*	*Iotrochota birotulata*	*V. reiswigi*
M. lamarckiana		*Ircinia campana*	*Xestospongia muta*
Oculina diffusa		*Ircinia felix*	
Porites astreoides		*Ircinia strobilina*	
P. branneri		*Monanchora barbadensis*	
P. colonensis		*Monanchora unguifera*	
P. porites divaricata		*Mycale laevis*	
P. porites furcata		*Mycale* sp.	
P. porites porites		*Myrmekioderma* sp.	
Scolymia sp.		*Neofibularia notilangere*	
Siderastrea radians		*Niphates amorpha*	
S. siderea		*N. digitalis*	
Solenastrea bournoni		*N. erecta*	
Steph. michelinii		*Oligoceras hemorrhages*	

Table 7. Total number of species per site for stony corals, gorgonians, and sponges. Data are based upon four 15-m^2 surveys conducted at each site (60 m^2). Noted are sites within Sanctuary Fully Protected Marine Zones (FPMZs) (*) and those adjacent to and seaward of FPMZs (**). ns = no survey conducted.

Habitat type/site location	Region	Stony corals	Gorgonians	Sponges
Offshore patch reef				
Inshore and SW of Pacific Reef	Biscayne	21	21	41
Inshore of Pacific Reef	Biscayne	20	21	42
West Washerwoman Shoal	Lower Keys	28	24	28
West of West Washerwoman	Lower Keys	28	21	33
Patch reef (Staghorn mound)				
Dry Tortugas National Park	Tortugas	5	ns	ns
Dry Tortugas National Park	Tortugas	4	ns	ns
Reef knoll				
Dry Tortugas National Park	Tortugas	23	15	39
Dry Tortugas National Park	Tortugas	17	ns	ns
Dry Tortugas National Park	Tortugas	16	ns	ns
High-relief spur and groove				
Bird Key Reef	Tortugas	29	22	43
Medium-profile reef				
Coal Bin (East of Cosgrove Shoal)	Marquesas	28	17	40
Cosgrove Shoal	Marquesas	20	14	35
Dry Tortugas National Park	Tortugas	20	ns	ns
Pulaski Shoal (just outside DTNP)	Tortugas	25	11	43
Patchy hard bottom in sand				
Between Star & Triumph Reef	Biscayne	13	23	40
North of Fowey Rocks	Biscayne	14	14	30
Low-relief hard-bottom				
SW of Pacific Reef	Biscayne	17	20	37
Ajax Reef	Biscayne	18	18	17
North of Ajax Reef	Biscayne	14	16	25
Star Reef	Biscayne	17	18	36
Ledberry Reef	Biscayne	14	12	35
East of Biscayne Bay	Biscayne	18	14	37
Carysfort Reef SPA*	Upper Keys	22	16	27
Seaward of Watson's Reef	Upper Keys	16	18	44
Between Molasses & French Reef	Upper Keys	19	15	38
Southern DTNP (just outside park)	Tortugas	16	20	43
Dry Tortugas National Park	Tortugas	21	23	38
Dry Tortugas National Park	Tortugas	15	21	42
Dry Tortugas National Park	Tortugas	25	22	48
Dry Tortugas National Park	Tortugas	18	ns	7
Dry Tortugas National Park	Tortugas	16	25	32
NW of Loggerhead Key	Tortugas	16	27	42
Dry Tortugas National Park	Tortugas	13	ns	ns
Tortugas Bank	Tortugas	19	13	35

Table 7. continued.

Habitat type/site location	Region	Stony corals	Gorgonians	Sponges
Low-relief spur and groove				
Offshore Pacific Reef	Biscayne	18	18	37
Between Star & Triumph Reef	Biscayne	18	18	43
SW of Brewster Reef	Biscayne	16	18	33
South of Fowey Rocks	Biscayne	17	7	37
Carysfort Reef SPA*	Upper Keys	16	13	38
Elbow Reef SPA**	Upper Keys	19	17	42
North Dixie Shoal	Upper Keys	18	13	31
Dixie Shoal	Upper Keys	19	18	39
French Reef**	Upper Keys	14	10	32
Molasses Reef**	Upper Keys	14	17	46
Conch Reef Research Only*	Middle Keys	19	12	39
Davis Reef**	Middle Keys	21	15	42
Alligator Reef**	Middle Keys	21	20	46
Between Tennessee & Alligator	Middle Keys	27	21	35
Offshore of Tennessee RO**	Middle Keys	23	16	36
East of Pelican Shoal	Lower Keys	16	24	34
Eastern Sambo**	Lower Keys	18	16	37
Western Sambo*	Lower Keys	27	10	32
Between W. Sambo & E. Dry Rocks	Lower Keys	22	9	22
Eastern Dry Rocks**	Lower Keys	23	18	39
Rock Key**	Lower Keys	22	19	41
Sand Key**	Lower Keys	23	20	38
SW of Western Dry Rocks	Lower Keys	24	19	44
Dry Tortugas National Park	Tortugas	30	14	40
Reef terrace				
Loggerhead Forest	Tortugas	28	7	25
Sherwood Forest	Tortugas	25	10	24
Sherwood Forest	Tortugas	25	9	31
Sherwood Forest	Tortugas	26	9	25
Sherwood Forest	Tortugas	19	ns	ns

Juvenile Coral Density

Surveys of juvenile coral species composition, density, and maximum diameter continued during 2002. Table 8 lists the density of juvenile scleractinian coral for each survey location. The highest juvenile coral densities were found on offshore patch reefs in the Lower Keys. Juvenile coral densities were relatively similar, but variable within and among habitat types in the Lower, Middle, and Upper Keys (excluding offshore patch reefs) and relatively higher than densities within and among habitats in the Biscayne area. The overall range of density values in the Dry Tortugas was similar to Keys-wide values, within and among habitat types. Medium-profile reefs exhibited the highest juvenile scleractinian coral densities overall. Within the low-relief spur and groove habitat among the Upper, Middle, and Lower Keys, mean juvenile densities were greatest in the Lower (7.1 juveniles/m^2) and Middle Keys (7.0 individuals per m^2) and significantly lower in the Upper Keys (4.7 juveniles/m^2) for the 10 sites surveyed in this region.

Table 8. Mean (1 SE) density (no. colonies/m^2) of scleractinian corals, juvenile scleractinian corals (< 4 cm max. diameter), and gorgonians. Noted are sites within Sanctuary Fully Protected Marine Zones (*) and sites adjacent to and seaward of zone boundaries (**). ns = no survey conducted.

Habitat type/site location	Scleractinian corals	SE	Juvenile corals	SE	Gorgonians	SE
Offshore patch reef						
Inshore and SW of Pacific Reef	3.15	0.01	3.21	0.00	19.88	0.03
Inshore of Pacific Reef	4.25	0.61	5.45	0.21	11.00	0.78
West Washerwoman Shoal	13.65	1.13	16.51	37.44	27.88	12.50
West of West Washerwoman	13.75	0.85	13.14	10.07	11.44	9.57
Patch reef (Staghorn mound)						
Dry Tortugas National Park	0.30	0.02	0.16	0.05	ns	ns
Dry Tortugas National Park	0.00	0.00	0.00	0.00	ns	ns
Reef knoll						
Dry Tortugas National Park	7.55	1.45	5.13	0.82	ns	ns
Dry Tortugas National Park	8.15	3.13	4.41	0.00	ns	ns
Dry Tortugas National Park	1.60	0.02	2.40	0.05	ns	ns
High-relief spur and groove						
Bird Key Reef	8.25	0.05	7.05	0.21	31.92	0.35
Medium-profile reef						
Coal Bin (East of Cosgrove Shoal)	4.65	0.41	8.81	6.22	23.00	2.72
Cosgrove Shoal	4.60	0.02	6.41	7.40	12.88	4.50
Dry Tortugas National Park	7.20	8.82	6.09	1.85	ns	ns
Pulaski Shoal (just outside park)	5.30	0.00	7.21	4.16	ns	ns
Patchy hard bottom in sand						
Between Star & Triumph Reef	2.35	0.13	4.81	0.82	10.69	21.95
North of Fowey Rocks	1.70	1.28	5.61	1.28	10.88	0.28
Low-relief hard-bottom						
SW of Pacific Reef	2.15	0.61	3.85	3.29	17.10	27.38
Ajax Reef	2.30	0.32	1.60	0.00	14.81	0.20
North of Ajax Reef	1.40	0.08	5.45	1.85	10.94	0.95
Star Reef	1.20	0.02	4.65	0.05	11.00	4.50
Ledberry Reef	0.95	0.13	3.53	5.14	15.06	0.07
East of Biscayne Bay	3.10	0.18	6.25	2.52	8.94	8.51
Carysfort Reef SPA*	7.15	1.13	9.13	4.16	5.38	4.50
Seaward of Watson's Reef	3.95	3.65	10.74	4.16	16.13	78.13
Between Molasses & French Reef	2.35	0.41	3.53	0.82	10.13	0.13
Southern DTNP (just outside park)	1.95	0.13	3.85	0.82	19.17	0.22
Dry Tortugas National Park	1.40	0.08	4.43	0.96	25.33	26.89
Dry Tortugas National Park	2.30	0.32	5.13	0.00	26.83	2.72
Dry Tortugas National Park	3.90	1.28	6.89	0.46	21.94	35.07
Dry Tortugas National Park	2.05	0.25	4.17	0.21	ns	ns
Tortugas Bank	2.05	0.25	5.93	4.16	ns	ns
Dry Tortugas National Park	0.90	0.00	2.40	2.52	27.85	0.13
NW of Loggerhead Key	0.90	0.18	0.96	0.00	ns	ns
Dry Tortugas National Park	1.60	0.72	2.56	0.00	ns	ns

Table 8. continued.

Habitat type/site location	Scleractinia	SE	Juvenile corals	SE	Gorgonians	SE
Low-relief spur and groove						
Offshore Pacific Reef	1.95	0.05	3.69	1.28	9.56	20.32
SW of Brewster Reef	5.00	2.00	3.04	4.16	27.19	3.45
South of Fowey Rocks	3.95	2.21	4.81	5.14	4.69	3.45
Between Star & Triumph Reef	1.80	0.18	4.49	3.29	14.06	2.26
Carysfort Reef SPA*	1.20	0.02	4.33	0.46	9.75	0.28
Elbow Reef SPA**	3.35	0.85	7.37	5.14	10.56	0.01
North Dixie Shoal	5.40	0.50	4.81	3.29	6.13	0.03
Dixie Shoal	5.25	0.25	5.93	8.68	10.56	2.26
French Reef **	2.95	3.65	4.49	0.21	19.81	4.88
Molasses Reef**	3.55	0.25	4.01	4.16	10.25	3.78
Conch Reef Research Only*	3.95	1.13	10.26	0.82	8.19	0.95
Davis Reef**	3.95	0.01	6.57	6.22	ns	ns
Alligator Reef**	2.10	2.00	3.85	3.29	ns	ns
Between Tennessee & Alligator	11.31	0.20	10.42	27.17	ns	ns
Offshore of Tennessee RO**	6.13	0.78	3.69	6.22	ns	ns
East of Pelican Shoal	2.85	0.61	10.90	1.85	15.13	0.00
Eastern Sambo**	4.75	0.85	6.57	1.28	ns	ns
Western Sambo*	4.50	0.50	3.77	0.12	ns	ns
Between W. Sambo & E. Dry Rocks	5.48	3.25	ns	ns	ns	ns
Eastern Dry Rocks**	5.50	0.50	3.69	6.22	ns	ns
Rock Key**	3.80	2.00	9.46	1.28	ns	ns
Sand Key**	2.75	1.81	6.53	2.34	ns	ns
SW of Western Dry Rocks	3.80	0.72	7.85	4.16	ns	ns
Dry Tortugas National Park	9.55	0.25	8.01	1.85	13.08	3.13
Reef terrace						
Loggerhead Forest	5.35	1.13	1.32	0.93	ns	ns
Sherwood Forest	7.90	0.72	3.04	6.22	ns	ns
Sherwood Forest	7.75	0.05	ns	ns	ns	ns
Sherwood Forest	7.20	0.08	6.13	12.74	ns	ns
Sherwood Forest	4.70	0.72	2.75	0.07	ns	ns

Gorgonian Density

Total gorgonian density for each site surveyed is listed in Table 8. From Biscayne to the Lower Keys, gorgonian densities were generally similar among habitats, regions, and management protection. The highest densities were recorded from offshore patch reefs in the Lower Keys. Only nine sites in the Dry Tortugas included surveys for gorgonian density due to logistical constraints (three divers instead of four). Among the Tortugas sites, the highest gorgonian densities were found in low-relief hard-bottom and high relief spur and groove (Bird Key Reef) habitats.

Urchin Density and Size

Surveys of urchin density were conducted at 56 of the 64 sites during 2002. Three species were encountered in transect surveys (Table 9). Similar to results from 1999-2001, all of the sampling locations yielded very low densities of urchins, particularly the long-spined sea urchin *Diadema antillarum*. However, we found some locations with relatively high densities of other species, particularly *Echinometra viridis*. Because densities remain low, patterns are difficult to discern,

Table 9. Mean (1 SE) densities of urchins (no. individuals per m^2) from surveys of four 15-m^2 plots per site. Noted are sites within Sanctuary Fully Protected Marine Zones (*) and those adjacent to and seaward of zone boundaries (**). ns = no survey conducted.

Habitat type/site location	***Diadema antillarum***		***Eucidaris tribuloides***		***Echinometra viridis***	
	Mean	SE	Mean	SE	Mean	SE
Offshore patch reef						
Inshore of Pacific Reef	0	0	0.017	0.001	0	0
West Washerwoman Shoal	0	0	0	0	0.711	0.099
West of West Washerwoman	0.017	0.001	0.017	0.001	1.033	0.336
Patch reef (Staghorn mound)						
Dry Tortugas National Park	0	0	0	0	0	0
Reef knoll						
Dry Tortugas National Park	0.017	0.001	0	0	0.150	0.007
High-relief spur and groove						
Bird Key Reef	0	0	0	0	0.217	0.046
Medium-profile reef						
Coal Bin (East of Cosgrove Shoal)	0	0	0	0	0	0
Cosgrove Shoal	0	0	0	0	0.017	0.001
Pulaski Shoal (just outside DTNP)	0	0	0	0	0	0
Patchy hard-bottom in sand						
Between Star & Triumph Reef	0.050	0.004	0	0	0.033	0.001
North of Fowey Rocks	0	0	0	0	0	0
Low-relief hard-bottom						
SW of Pacific Reef	0	0	0	0	0	0
Ajax Reef	0	0	0.017	0.001	0.017	0.001
North of Ajax Reef	0	0	0	0	0	0
Star Reef	0	0	0	0	0	0
Ledberry Reef	0	0	0	0	0	0
East of Biscayne Bay	0	0	0	0	0	0
Carysfort Reef SPA*	0	0	0	0	0	0
Seaward of Watson's Reef	0	0	0	0	0.050	0.010
Between Molasses & French Reef	0	0	0.017	0.001	0.017	0.001
Southern DTNP (just outside park)	0	0	0.017	0.001	0	0
Dry Tortugas National Park	0	0	0.017	0.001	0	0
Dry Tortugas National Park	0	0	0	0	0	0
Dry Tortugas National Park	0	0	0	0	0.017	0.001
Tortugas Bank	0	0	0	0	0	0
Dry Tortugas National Park	0.022	0.001	0	0	0	0
NW of Loggerhead Key	0	0	0	0	0	0

Table 9. continued.

Habitat type/site location	*Diadema antillarum*		*Eucidaris tribuloides*		*Echinometra viridis*	
	Mean	SE	Mean	SE	Mean	SE
Low- relief spur and groove						
Offshore Pacific Reef	0	0	0	0	0	0
Between Star & Triumph Reef	0.017	0.001	0	0	0	0
SW of Brewster Reef	0	0	0.017	0.001	0	0
South of Fowey Rocks	0	0	0	0	0	0
Carysfort Reef SPA*	0	0	0	0	0	0
Elbow Reef SPA**	0	0	0	0	0	0
North Dixie Shoal	0	0	0	0	0	0
Dixie Shoal	0	0	0	0	0	0
French Reef**	0	0	0	0	0	0
Molasses Reef**	0	0	0	0	0	0
Conch Reef Research Only*	0	0	0	0	0	0
Davis Reef**	0	0	0	0	0	0
Alligator Reef**	0	0	0	0	0	0
Between Tennessee & Alligator	0	0	0.017	0.001	0	0
Offshore of Tennessee RO**	0.022	0.001	0	0	0	0
East of Pelican Shoal	0	0	0	0	0	0
Eastern Sambo Reef**	0	0	0	0	0	0
Western Sambo Reef*	0	0	0	0	0	0
Between W. Sambo & E. Dry Rocks	0	0	0	0	0	0
Eastern Dry Rocks	0	0	0	0	0	0
Rock Key**	0	0	0	0	0.017	0.001
Sand Key**	0	0	0	0	0	0
SW of Western Dry Rocks	0	0	0.022	0.001	0	0
Dry Tortugas National Park	0	0	0	0	0	0
Reef terrace						
Loggerhead Forest	0	0	0	0	0	0
Sherwood Forest	0	0	0	0	0	0
Sherwood Forest	0.022	0.001	0	0	0	0
Sherwood Forest	0	0	0	0	0.017	0.001
Sherwood Forest	0	0	0	0	0.017	0.001

although we detected an abundance of *E. viridis* on offshore patch reefs compared to *Eucidaris tribuloides*, from Biscayne Bay to Key West.

Incidental Invertebrates

We assessed density patterns at 18 of the 64 sites surveyed for a variety of sessile and mobile invertebrate species during 2002 (Table 10). These surveys were not included at all sites for logistical reasons (three divers instead of four). In addition to anemones and corallimorpharians (Table 11), three species of shrimp symbionts, the polychaete *Hermodice caruncullata*, the basket star *Astrophyton muricatum*, and crustaceans were counted within strip transect surveys at a number of sites (Table 12).

Table 10. Incidental marine invertebrates surveyed for density during 2002. Listed are only those species recorded within four 15-m^2 plots per site.

Invertebrate group	Species name	Common name
Anemones	*Bartholomea annulata*	Ringed anemone
	Condylactis gigantea	Pink-tipped anemone
	Lebrunia danae	
Corallimorpharians	*Ricordea florida*	Florida corallimorph
Polychaetes	*Hermodice caruncullata*	Fire worm
Echinoderms	*Astrophyton muricatum*	Basket star
	Diadema antillarum	Long-spined sea urchin
	Echinometra viridis	Reef urchin
	Eucidaris tribuloides	Red pencil urchin
Crustaceans	*Panulirus argus*	Spiny lobster
	Periclimenes pedersoni	Pederson's cleaner shrimp
	Stenorhyncus seticornis	Arrow crab
	Stenopus hispidus	Red-banded coral shrimp

Table 11. Mean (1 SE) densities (no. individuals per m^2) of anemones and corallimorpharians from surveys of four 15-m^2 plots per survey location. Sites within Sanctuary Fully Protected Marine Zones are noted with a single asterisk (*) and sites adjacent to and seaward of zone boundaries are double asterisked (**). Listed are only the sites surveyed and species recorded within four 15-m^2 plots per site.

Habitat type/site location	*Bartholomea annulata*	*Condylactis gigantea*	*Lebrunia danae*	*Ricordea florida*
Offshore patch reef				
Inshore of Pacific Reef	0.033 (0.004)	0.017 (0.001)	0.017 (0.001)	0
Patchy hard-bottom in sand				
Between Star & Triumph Reef	0.033 (0.001)	0.033 (0.001)	0	0.150 (0.022)
North of Fowey Rocks	0.017 (0.001)	0	0	0
Low-relief hard bottom				
Ajax Reef	0.050 (0.010)	0	0	0
North of Ajax Reef	0	0	0	0
Star Reef	0	0	0	0
Ledberry Reef	0	0	0	0
East of Biscayne Bay	0.017 (0.001)	0	0	0
Low-relief spur and groove				
Offshore Pacific Reef	0	0	0	0
Between Star & Triumph Reef	0.033 (0.001)	0	0	0
SW of Brewster Reef	0	0	0	0.017 (0.001)
South of Fowey Rocks	0.033 (0.004)	0	0	0
North Dixie Shoal	0.033 (0.001)	0.050 (0.004)	0	0
French Reef **	0	0	0	0
East of Pelican Shoal	0	0	0.017 (0.001)	0
Eastern Sambo**	0	0	0	0
Western Sambo*	0	0	0	0
Between W. Sambo & E. Dry Rocks	0.017 (0.001)	0	0	0

Table 12. Mean (1 SE) densities (no. individuals per m^2) of incidental marine invertebrates from surveys of four 15-m^2 plots per survey location. Noted are sites within Sanctuary Fully Protected Marine Zones (*) and sites adjacent to and seaward of the zones (**). Listed are only those sites surveyed where species were found within four 15-m^2 plots at each site.

Habitat type/site location	*Astrophyton muricatum*	*Periclimenes pedersoni*	*Stenopus hispidus*	*Stenorhyncus seticornis*
Offshore patch reef				
Inshore of Pacific Reef	0	0	0.033 (0.002)	0
Patchy hard-bottom in sand				
Between Star & Triumph Reef	0.133 (0.009)	0	0	0.017 (0.001)
North of Fowey Rocks	0.233 (0.016)	0	0	0
Low-relief hard- bottom				
Ajax Reef	0	0	0	0
North of Ajax Reef	0.067 (0.003)	0	0	0
Star Reef	0.133 (0.033)	0	0	0
Ledberry Reef	0.333 (0.086)	0	0	0.017 (0.001)
East of Biscayne Bay	0	0	0.017 (0.001)	0.033 (0.004)
Low-relief spur and groove				
Offshore Pacific Reef	0.067 (0.018)	0	0	0.017 (0.001)
Between Star & Triumph Reef	0	0	0	0
SW of Brewster Reef	0	0	0	0.017 (0.001)
South of Fowey Rocks	0.083 (0.010)	0.033 (0.004)	0.017 (0.001)	0.033 (0.002)
North Dixie Shoal	0.083 (0.010)	0.017 (0.001)	0.017 (0.001)	0.033 (0.002)
French Reef**	0	0	0	0.017 (0.001)
East of Pelican Shoal	0.017 (0.001)	0	0	0
Eastern Sambo**	0.017 (0.001)	0	0	0
Western Sambo*	0	0	0	0.017 (0.001)
Between W. Sambo & E. Dry Rocks	0	0	0	0

Plans for Use of the Data

We have made significant progress in manuscript development since January 2002. Below is a listing of manuscripts in press or published, those submitted for review, and those we intend to submit for publication by January 2003. We plan on using the 2002 data collected from the deeper fore reef to compare to a similar Keys-wide study conducted in 1995 of low-relief spur and groove habitats at 15-21 m depth.

Manuscripts Published

1. Ault JS, Smith SG, Meester GA, Luo J, Bohnsack JA, Miller SL (2002) *Baseline multispecies coral reef fish stock assessment for the Dry Tortugas*. NOAA Technical Memorandum NMFS-SEFSC-487, 117 p.
2. Ault JS, Smith SG, Meester GA, Luo J, Franklin EC, Bohnsack JA, Harper DE, McClellan DB, Miller SL, Swanson DW, Chiappone M (2002) Tortugas surveyed: Synoptic habitat and reef fish surveys support establishment of marine reserves in the Dry Tortugas, Florida, USA. *Reef Encounter* 31: 22-23.
3. Chiappone M, Miller SL, Swanson DW, Ault JS, Smith SG (2001) Comparatively high densities of the long-spined sea urchin in the Dry Tortugas, Florida. *Coral Reefs* 20: 137-138.

4. Chiappone M, Miller SL, Swanson DW (2001) *Condylactis gigantea* – A giant comes under pressure from the aquarium trade in Florida. *Reef Encounter* 30: 29-31.
5. Chiappone M, Swanson DW, Miller SL (2002) Density, spatial distribution and size structure of sea urchins in coral reef and hard-bottom habitats of the Florida Keys. *Marine Ecology Progress Series* 235: 117-126.
6. Chiappone M, Swanson DW, Miller SL, Smith SG (2002) Large-scale surveys on the Florida Reef Tract indicate poor recovery of the long-spined sea urchin *Diadema antillarum*. *Coral Reefs* 21: 155-159.
7. Chiappone M, White A, Swanson DW, Miller SL (2002) Occurrence and biological impacts of fishing gear and other marine debris in the Florida Keys. *Marine Pollution Bulletin* 44: 597-604.
8. Miller SL, Chiappone M, Swanson DW, Ault JS, Smith SG, Meester GA, Luo J, Franklin EC, Bohnsack JA, Harper DE, McClellan DB (2001) An extensive deep reef terrace on the Tortugas Bank, Florida Keys National Marine Sanctuary. *Coral Reefs* 20: 299-300.

Manuscripts in Press

9. Chiappone M, Dienes H, Swanson DW, Miller SL (In press) Density and gorgonian host-occupation patterns by flamingo tongue snails (*Cyphoma gibbosum*) in the Florida Keys. *Caribbean Journal of Science.*
10. Dienes H, Chiappone M, Miller SL, Swanson DW (In press) Density and fore reef habitat utilization patterns of the lettuce sea slug (*Tridachia crispata*) in the Florida Keys. *Bulletin of Marine Science.*
11. Dienes H, Chiappone M, Swanson DW, Miller SL (In press) Impacts of lost fishing gear on coral reef sessile invertebrates of the Florida Keys National Marine Sanctuary. *Biological Conservation.*
12. Franklin EC, Ault JS, Smith SG, Luo J, Meester GA, Diaz GA, Chiappone M, Swanson DW, Miller SL, Bohnsack JA (In press) Coral reef benthic habitat classification in the Tortugas region, Florida. *Marine Geodesy*.
13. Miller SL, Swanson DW, Chiappone M (In press) Multiple spatial scale assessment of coral reef and hard-bottom community structure in the Florida Keys National Marine Sanctuary. *Proceedings of the 9th International Coral Reef Symposium, Bali.*

Manuscripts in Review

14. Chiappone M, Swanson DW, Miller SL (In review) Density and habitat utilization patterns of anemones and corallimorpharians (Anthozoa, Zoantharia) in the Florida Keys National Marine Sanctuary. *Coral Reefs.*
15. Chiappone M, Swanson DW, Miller SL (In review) Large-scale density patterns of anemones and corallimorpharians on offshore coral reef habitats in the Florida Keys. *Bulletin of Marine Science.*
16. Dienes H, Chiappone M, Swanson DW, Miller SL (In review) Spatial distribution and density of fishing gear in Florida Keys National Marine Sanctuary no-take zones. *Coral Reefs.*
17. Precht WF, Miller SL (2002) Ecological shifts along the Florida reef tract: Is the past the key to the future? In *The destruction of coral reef ecosystems: Paleoecological perspectives on the human role in a global crisis*. Aronson RB (ed), Springer Verlag, NY.

Manuscripts in Progress

18. Chiappone M, Swanson DW, Miller SL (In progress) Impacts to coral reef sessile invertebrates from lost lobster trap gear in the Florida Keys National Marine Sanctuary. *Symposium on Effects of Fishing Activities on Benthic Habitats, American Fisheries Society*.
19. Chiappone M, Swanson DW, Miller SL (In progress) Spatial distribution and impacts of lost hook-and-line fishing gear to sessile invertebrates in the Florida Keys National Marine Sanctuary. *Symposium on Effects of Fishing Activities on Benthic Habitats, American Fisheries Society*.
20. Chiappone M, Swanson DW, Miller SL, Sullivan-Sealey KM (In progress) A hierarchical structural classification of Florida Keys coral reef and hard-bottom habitats. *Aquatic Conservation: Marine and Freshwater Ecosystems.*
21. Chiappone M, Swanson DW, Miller SL, White A, Dienes H (In progress) A rapid method for assessing topographic complexity of coral reef and hard-bottom habitats. *Journal of Experimental Marine Biology and Ecology*.
22. Miller SL, Chiappone M, Swanson DW (In progress) Long-term dynamics of Florida Keys acroporid reefs: History and implications of a phase shift. *Coral Reefs.*
23. Miller SL, Chiappone M, Swanson DW, Ault JS, Smith SG, Franklin EC (In progress) Design-based surveys of coral reef and hard-bottom habitats in Dry Tortugas National Park and the Tortugas Bank, Florida. *Ecological Applications.*
24. Miller SL, Gittings S, Chiappone M, Causey B, Swanson DW, White A (In progress) Changes (1994-2000) to benthic cover on a deep coral reef in the Florida Keys. *Coral Reefs.*
25. Smith SG, Swanson DW, Miller SL, Ault JS, Chiappone M (In progress) Sampling survey approaches for coral reef assessment and monitoring in the Florida Keys. *Coral Reefs.*
26. Swanson DW, Chiappone M, Miller SL (In progress) Habitat and regional variations in coral species richness and coverage in the Florida Keys. *Coral Reefs.*
27. Swanson DW, Chiappone M, Miller SL (In progress) Disease prevalence on reef-building corals in the Florida Keys National Marine Sanctuary. *Marine Ecology Progress Series.*

Preliminary Analysis of FKNMS Reef Fish Monitoring Through 2002

James A. Bohnsack, David B. McClellan, and Douglas E. Harper (NOAA/National Marine Fisheries Service, Miami, FL)
Jerry Ault, Steven G. Smith, Geoff Meester, and Jiangang Luo (RSMAS, University of Miami, Miami, FL)

Goal

The goal of this monitoring is to assess changes in reef fish populations in zones under different levels of protective management. On July 1, 1997 the FKNMS established 18 fully protected ("no-take") Sanctuary Preservation Areas (SPAs) and one Ecological Reserve in the Western Sambo region of the lower Keys. Field studies since then have been directed at comparing changes in Fully Protected Marine Zones (FPMZs) to nearby reference areas with fishing.

Methods

Sampling continued through 2002, the fifth full year of protection. The sampling design was improved in 1999 to include a habitat-based, stratified random sampling design and expanded into other habitats to more efficiently monitor reef fish populations throughout the Florida Keys and to better assess habitat preferences by different species. This expanded effort added two classes of data (random samples of low-relief habitat in protected and fished areas) in addition to the high-relief protected and fished sites previously sampled. In 2002, field sampling was successfully completed for a total of 306 reef blocks and 1,224 dives from Dade County through the lower Keys (Fig. 1). These sites include a total of 278 stratified random blocks and 28 historical reference reef sites. Each block represents four stationary fish counts.

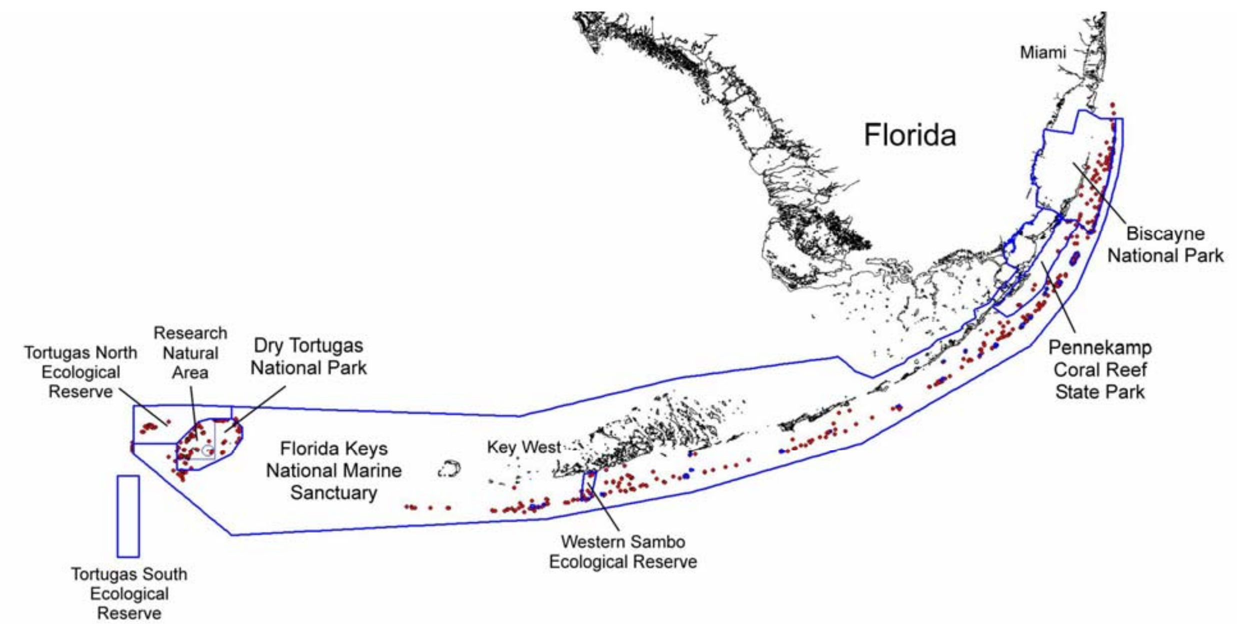


Figure 1. Location of stationary fish sample sites in the Florida Keys National Marine Sanctuary, Biscayne National Park, and Dry Tortugas National Park sampled during the 2002 Keys-wide cruise.

Findings to Date

Below we show trend analyses of raw data from fished and unfished areas for selected targeted and non-targeted species. In the fall of 1998 Hurricane Georges, a large hurricane, and Hurricane Mitch, a small hurricane hit the Florida Keys. In 1999 Hurricane Irene, a small hurricane passed over the lower Keys. Yellowtail Snapper mean density continued to be significantly higher in FPMZs than fished sites and further increased above the long-term 1994-1997 performance range relative to fished reference areas (Fig. 2).

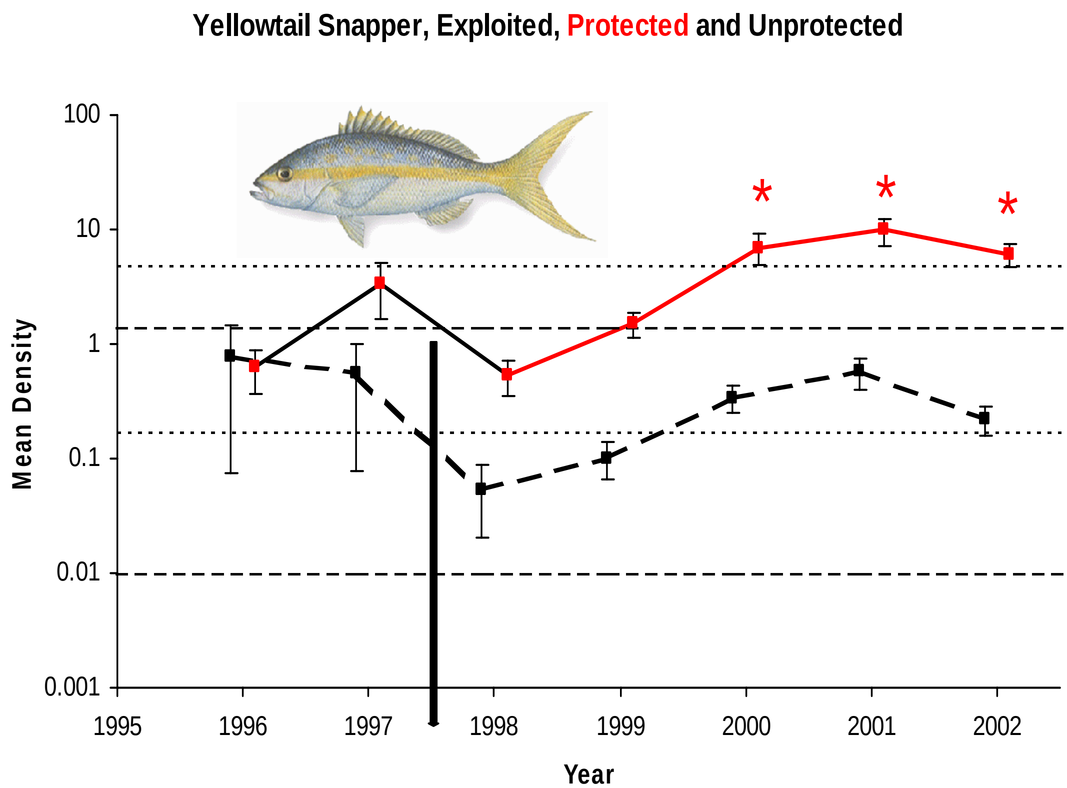


Figure 2. Comparison of Yellowtail Snapper density (log scale) trends in fully protected “no-take” Sanctuary Preservation Areas (SPAs) (solid upper line) and exploited reference areas (dashed lower line). Vertical line shows when no-take protection initiated. Horizontal finely dashed (SPAs) and darker dashed (reference areas) bands show null model predictions based on 1994-1997 95% annual performance measures projected to 2003. Whiskers show 95% confidence intervals. Asterisks denote significantly different densities from the “no significant change” projection.

Mean Black Grouper density has increased in both fished reference areas and FPMZs since 1997 and currently is approximately an order of magnitude higher than that in the baseline period. Densities in FPMZs have increased faster that in fished reference areas (Fig. 3).

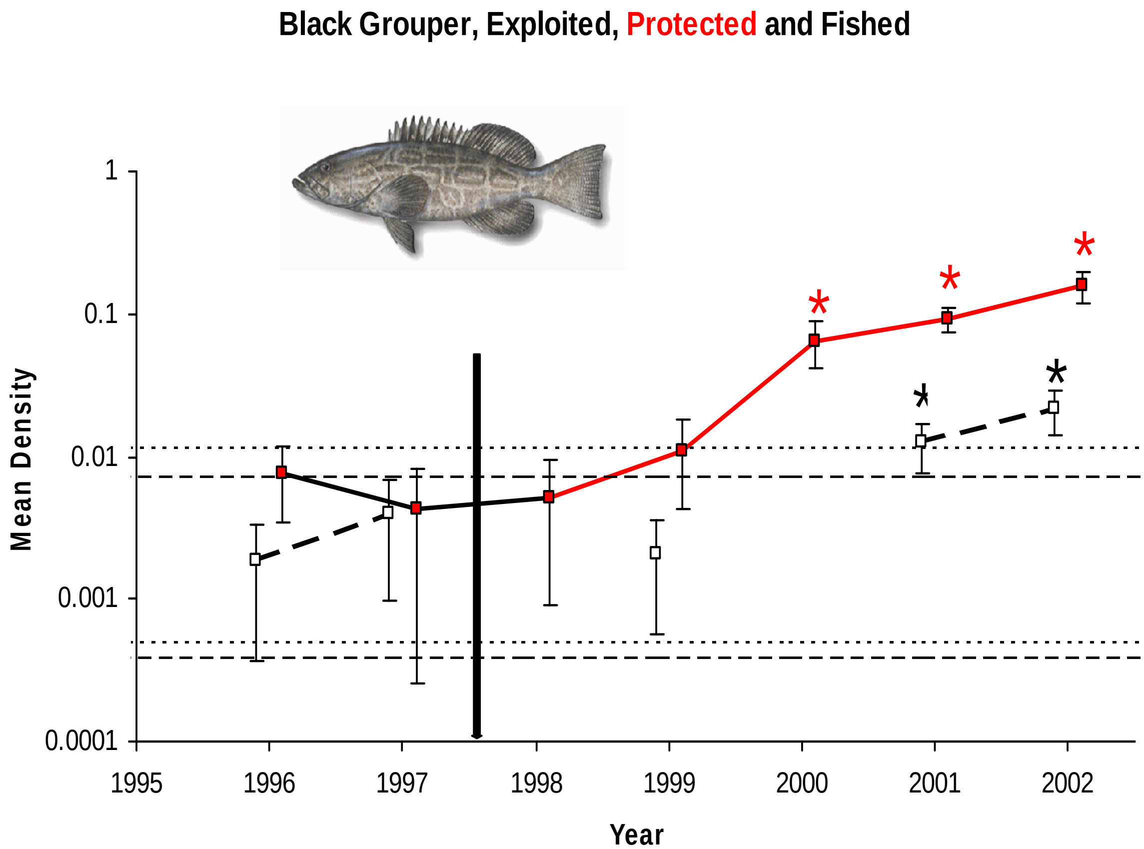


Figure 3. Comparison of Black Grouper density (log scale) trends in fully protected "no-take" Sanctuary Preservation Areas (SPAs) (solid upper line) and exploited reference areas (dashed lower line). Vertical line shows when no-take protection initiated. Horizontal dotted (SPAs) and dashed (reference areas) bands show null model predictions based on 1994-1997 95% annual performance measures projected to 2003. Whiskers show 95% confidence intervals. Asterisks denote significantly different densities from the "no significant change" projection.

Gray Snapper density also increased in both fished reference areas and FPMZs since 1997. Densities have remained higher in fully protected zones than in fished reference areas every year since 1997 and were somewhat higher prior to this (Fig. 4).

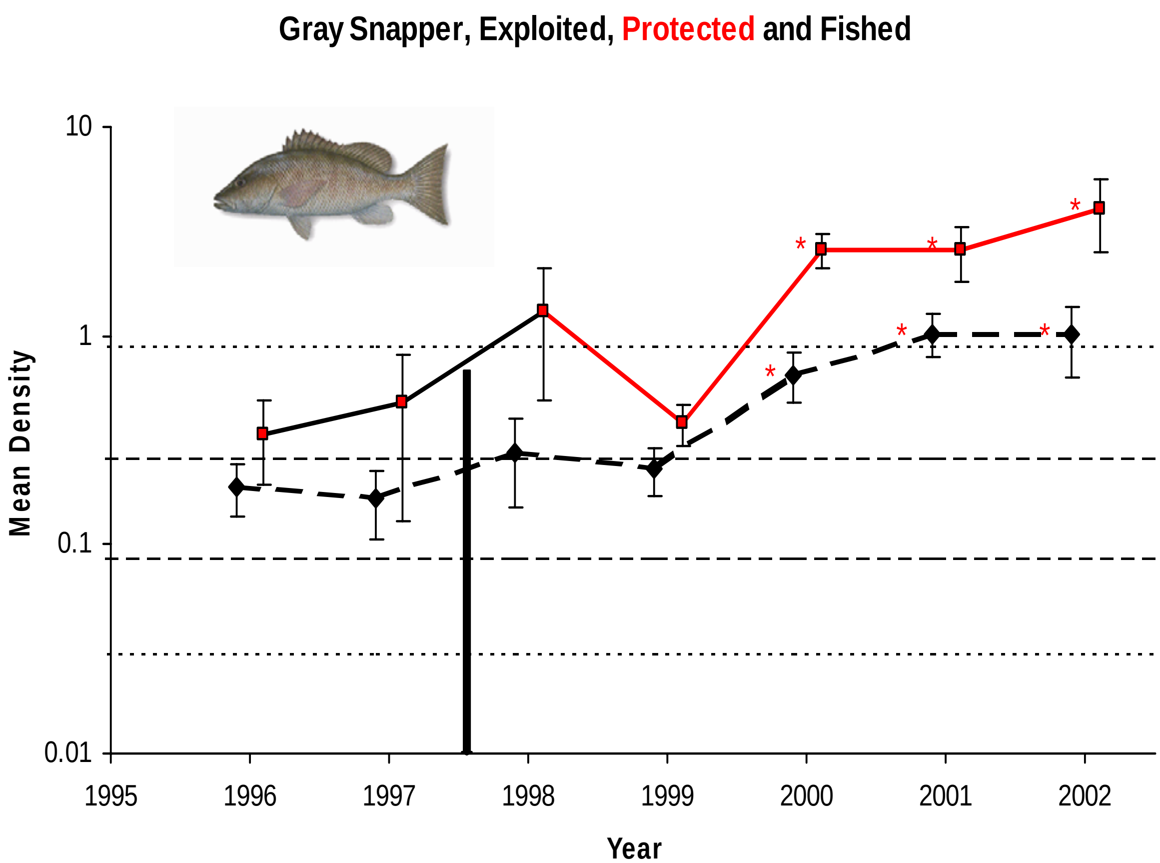


Figure 4. Comparison of Gray Snapper density (log scale) trends in fully protected "no-take" Sanctuary Preservation Areas (SPAs) (solid upper line) and exploited reference areas (dashed lower line). Vertical line shows when no-take protection initiated. Horizontal dotted/dashed (SPAs) and dashed/dotted (reference areas) bands show null model predictions based on 1994-1997 95% annual performance measures projected to 2003. Whiskers show 95% confidence intervals. Asterisks denote significantly different densities from the "no significant change" projection.

Stoplight Parrotfish, a large herbivore not normally targeted by fishing, have fluctuated in both fished and unfished areas (Fig. 5). Mean density was higher in unfished areas than in fished areas. Densities in FPMZs were generally within the long-term, 1994-1997, performance range, but generally remained slightly below the performance range in fished zones.

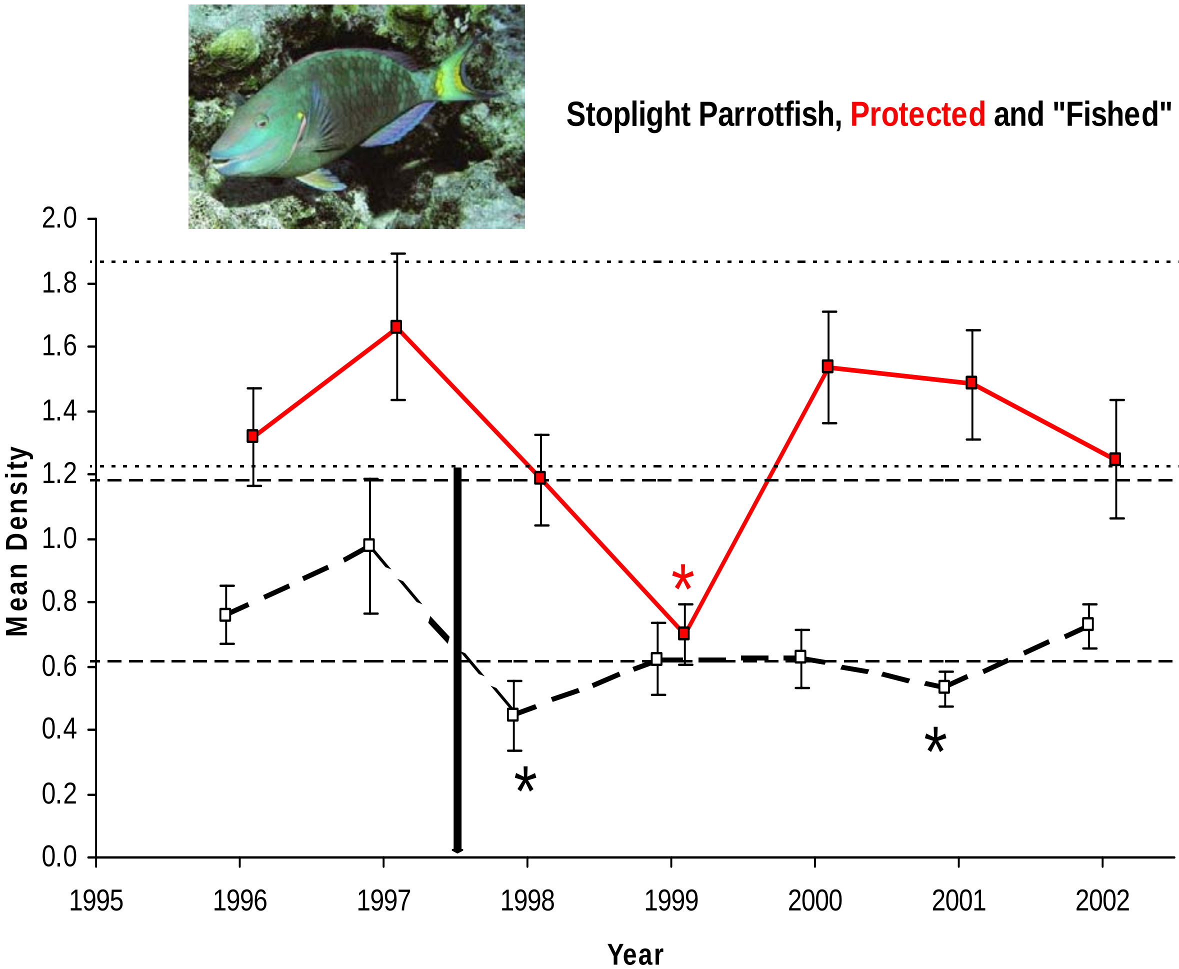


Figure 5. Comparison of Stoplight Parrotfish density trends in fully protected “no-take” Sanctuary Preservation Areas (SPAs) (solid upper line) and exploited reference areas (dashed lower line). Vertical line shows when no-take protection initiated. Horizontal dotted (SPAs) and dashed (reference areas) bands show null model predictions based on 1994-1997 95% annual performance measures projected to 2003. Whiskers show 95% confidence intervals. Asterisks denote significantly different densities from the “no significant change” projection.

Striped Parrotfish, a small herbivore not targeted by fishing, showed high concordance in mean density (number of individuals per sample) in both fished and unfished areas over the study period (Fig. 6). Density is slightly above the long-term performance range in FPMZs, but similar in fished and unfished areas.

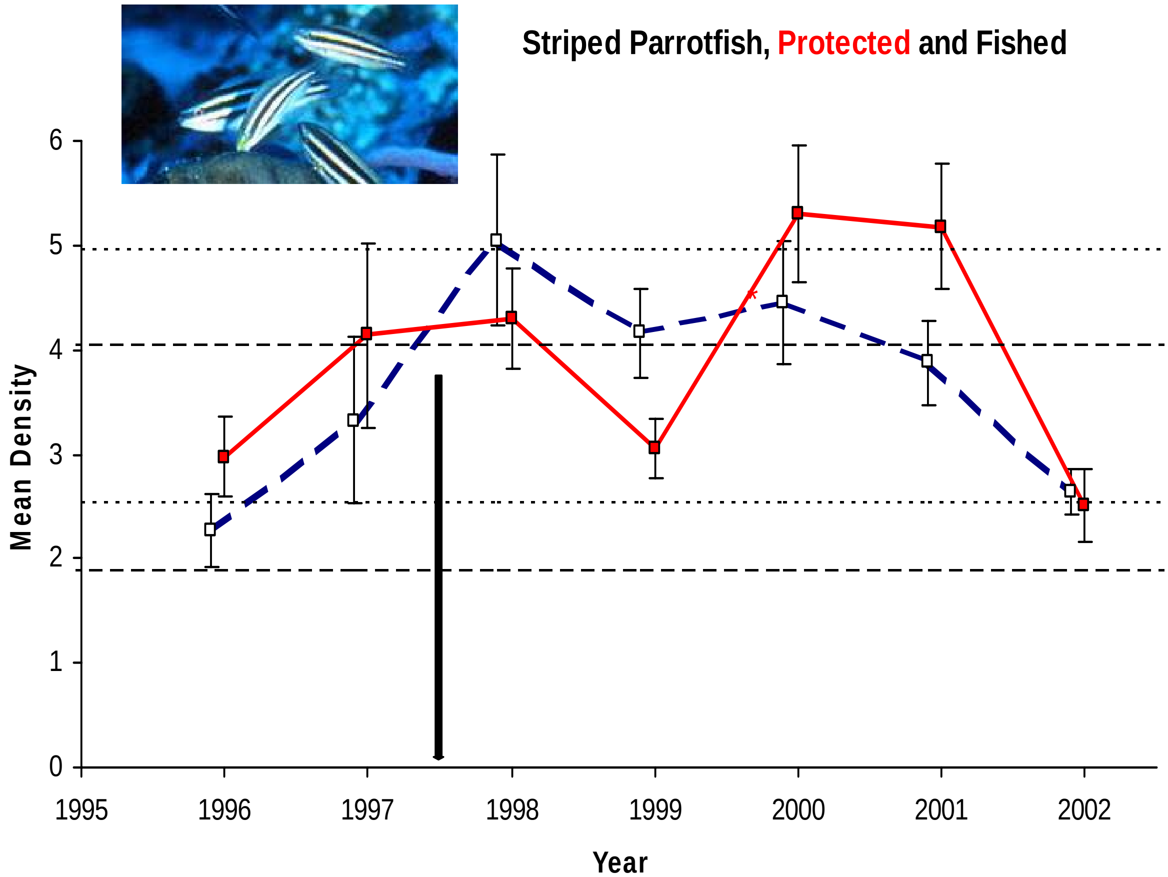


Figure 6. Comparison of Striped Parrotfish density trends in fully protected "no-take" Sanctuary Preservation Areas (SPAs) (solid upper line) and exploited reference areas (dashed lower line). Vertical line shows when no-take protection initiated. Horizontal dotted (SPAs) and dashed (reference areas) bands show null model predictions based on 1994-1997 95% annual performance measures projected to 2003. Whiskers show 95% confidence intervals. Asterisks denote significantly different densities from the "no significant change" projection.

Summary

Since no-take protection was initiated in 1997, significant density increases were observed for several exploited species in FPMZs compared to fished reference areas. Among exploited species, mean densities were higher in FPMZs for Gray Snapper, Black Grouper, and Yellowtail Snapper. Concordance was observed in changes in density for Stoplight Parrotfish and Striped Parrotfish, two species not directly exploited. The passage of Hurricane Georges (a strong hurricane) and Mitch (a weak hurricane) in the fall of 1998 resulted in declines of mean density at both fished and unfished sites in 1999 for the two non-exploited parrotfishes and Gray Snapper. No detrimental impacts on fish densities were noted following the passage of Hurricane Irene, a weak hurricane that passed over the Lower Keys in the fall of 1999.

Volunteer Reef Fish Monitoring in the Florida Keys National Marine Sanctuary: 2002 Update Report

Reef Environmental Education Foundation (REEF) staff and the REEF Advanced Assessment Team
Report compiled by Christy Pattengill-Semmens, REEF Scientific Coordinator

Survey Method

The Roving Diver Technique (RDT) is a non-point visual survey method designed to generate a comprehensive species list along with frequency and abundance estimates. During RDT surveys, a diver swims freely throughout a dive site and records every observed fish species. At the conclusion of each survey, the diver assigns each recorded species one of four $\log_{10}$ abundance categories [single (1); few (2-10), many (11-100), and abundant (> 100)]. Following the dive, each surveyor records the species data along with survey time, depth, temperature, and other environmental information on a REEF scansheet. The scansheets are returned to REEF, and the data are loaded into the REEF database that is publicly-accessible on the Internet at http://www.reef.org.

This project supports a team of the most experienced surveyors at REEF, the Advanced Assessment Team (AAT), to annually survey 37 sites in the FKNMS, including 12 SPAs, three Research-Only Areas, the Western Sambo Ecological Reserve, 10 sites in the Tortugas Ecological Reserve area, and 11 comparison/reference sites. A minimum of six RDT surveys is conducted at each site. The 2002 field season was the sixth year that the AAT has monitored most of these sites and the ninth full year of REEF volunteer data collection in the Sanctuary.

During the 2002 field season, the REEF AAT conducted 449 RDT surveys at the 37 monitoring sites, documenting 275 fish species. These data were collected during a series of cruises in August and September, and complement the REEF Fish Survey Project, a continual volunteer monitoring project that involves REEF volunteers conducting RDT surveys during their regular diving activities in the Florida Keys. Through the end of 2002, REEF volunteers had contributed 11,610 surveys from over 350 sites in the FKNMS and documented 431 fish species.

Findings to Date

This report summarizes all REEF data collected at the 27 Marine Zone Monitoring Program sites in the FKNMS between 1994 and 2002 (does not include the 10 Dry Tortugas sites). Table 1 lists the sites, along with the level of protection (if any) implemented in 1997 and annual REEF survey effort. These data were used to evaluate change over time in abundance score, a weighted average of the abundance categories reported for each species combined with the non-sightings[1], for several species, including species that are targeted for recreational fishing (grouper, snapper, and hogfish) and collected by marine life collectors (angelfish). Sighting frequency is shown for grouper, rather than abundance score, because it is a more sensitive measure of change for species that, when sighted, only one or few individuals are seen.

[1] abundance score = $[(n_S x1)+(n_F x2)+(n_M x3)+(n_A x4)] / (n_S + n_F + n_M + n_A)$ * percent sighting frequency, where n is the number of times each abundance category was assigned

Figure 1 shows sighting frequency over time at FPMZ and reference sites for three species of grouper (black grouper, *Mycteroperca bonaci*; Nassau grouper, *Epinephelus striatus*; and red grouper, *E. morio*). Black grouper has exhibited a significant increase throughout the Florida Keys between 1994 and 2002. In general, since sites were protected in 1997, black grouper have been seen with higher frequency in FPMZs than in reference areas. Two exceptions are Grecian Rocks and Cannon Patch, where black grouper have exhibited statistically significant (alpha = 0.10) decreases in abundance score during this time. Nassau grouper, a protected species in Florida, has shown slight increases over time and in 2002 reached an all time high of 22% sighting frequency at FPMZs since REEF data collection began. Red grouper, a relatively rare species, had increased at many sites in 1999 and 2000, but sighting frequency has decreased over the last two years.

The average abundances of four carnivore species (gray snapper, *Lutjanus griseus*; yellowtail snapper, *Ocyurus chrysurus*; schoolmaster, *L. apodus*; and hogfish, *Lachnolaimus maximus*) are shown in Figure 2. Data from all 27 sites are combined here because there was little difference between protected and unprotected sites. Yellowtail snapper and schoolmaster populations at these sites appear to be relatively stable between 1994 and 2002. Hogfish and gray snapper exhibited an increase in 1997.

The average abundances of four common angelfish species (Gray angelfish, *Pomacanthus arcuatus*; queen angelfish, *Holocanthus ciliarus*; French angelfish, *P. paru*; and rock beauty, *H. tricolor*) are shown in Figure 3. A dramatic decline in rock beauty has been seen, while the other angelfish populations have remained relatively stable. A potential cause of this decline is collecting for the aquarium industry; juvenile rock beauty is a popular fish for home aquaria. Using data on ornamental collection for Monroe County obtained from the Florida Fish and Wildlife Conservation Commission (FWC), the total number of rock beauty collected from 1990 – 2002 was evaluated. The number collected has decreased over the last decade, from a high of over 13,000 individuals in 1990 to 3,200 fish in 2002. Using REEF data from all sites in the FKNMS, the average abundance of rock beauty was calculated. A similar pattern in abundance to that seen at the 27 monitoring sites was seen when all sites were included. Figure 4 compares the FKNMS abundance with the number of individuals collected.

The yearly average abundance scores for four fished species (gray snapper, yellowtail snapper, schoolmaster, and black grouper) were compared among the three Sambo sites - Western Sambo Ecological Reserve, the largest no-take site in the main Florida Keys; Eastern Sambo Research-Only Area, a small area with permitted entry only; and Middle Sambo, an area between the two FPMZs that is open to exploitation. In general, the abundances of all four species were consistently higher at the FPMZs than at the open site and abundances at the Western Sambo Ecological Reserve were higher than at Eastern Sambo (Fig. 5).

Future Plans

The REEF AAT project in the FKNMS has ensured that annual data collection in the protected and reference areas by REEF experts occurs. While the initial 5-year project has been completed, REEF plans to continue this annual monitoring effort and completed another round of monitoring in 2002. REEF will also continue to enable all divers to participate in its volunteer Fish Survey Project in the FKNMS.

Table 1. REEF survey effort by location and by year. Effort includes all Species and Abundance RDT surveys conducted during daylight hours (after 7am and before 8pm) greater than 20 minutes in length.

		REEF Survey Effort								
Location	Protection	1994	1995	1996	1997	1998	1999	2000	2001	2002
Ball Buoy Reef	Open	0	0	0	7	5	14	13	14	8
Grecian Rocks	SPA	27	17	26	30	10	43	74	60	29
Carysfort Reef	SPA	17	18	0	8	10	21	23	17	41
Molasses Reef	SPA	31	28	20	47	84	125	85	214	309
Little Grecian	Open	1	10	3	13	7	10	15	10	7
South Carysfort Reef	SPA	0	12	14	6	7	15	14	12	7
Cannon Patch	Open	0	0	0	6	16	1	14	21	11
Pickles Reef	Open	1	1	1	25	15	12	36	23	31
Conch Reef	SPA	37	21	7	32	11	19	16	47	26
Hen and Chickens	SPA	23	8	8	19	15	12	12	22	17
Tennessee Reef Research	R-OA	34	0	0	16	9	9	8	12	8
Cheeca Rocks	SPA	0	0	0	17	11	9	6	13	9
Sombrero Reef	SPA	87	5	15	20	14	16	13	13	12
Samantha's Ledge	Open	38	0	6	13	11	12	15	13	10
Coffins Patch	SPA	35	0	5	6	28	11	10	14	9
Looe Key East	SPA	19	1	0	10	21	19	39	42	39
Looe Key Research	R-OA	18	0	0	6	8	13	9	12	10
Delta Shoals	Open	0	0	0	12	6	11	9	11	8
Newfound Harbor SPA	SPA	0	0	0	6	6	10	17	13	11
Newfound Harbor Open	Open	0	0	0	6	6	10	9	12	9
No Name Reef	Open	0	0	0	6	6	10	9	12	8
Western Sambo	ER	40	34	19	7	15	10	14	105	58
Eastern Sambo	SPA	25	18	0	12	9	8	11	20	11
Sand Key	SPA	15	45	11	14	17	11	13	29	42
Middle Sambo	Open	13	18	0	11	9	9	12	20	13
Pelican Shoals	Open	13	16	10	0	0	0	11	24	22
Western Dry Rocks	Open	1	0	0	19	19	16	11	37	22

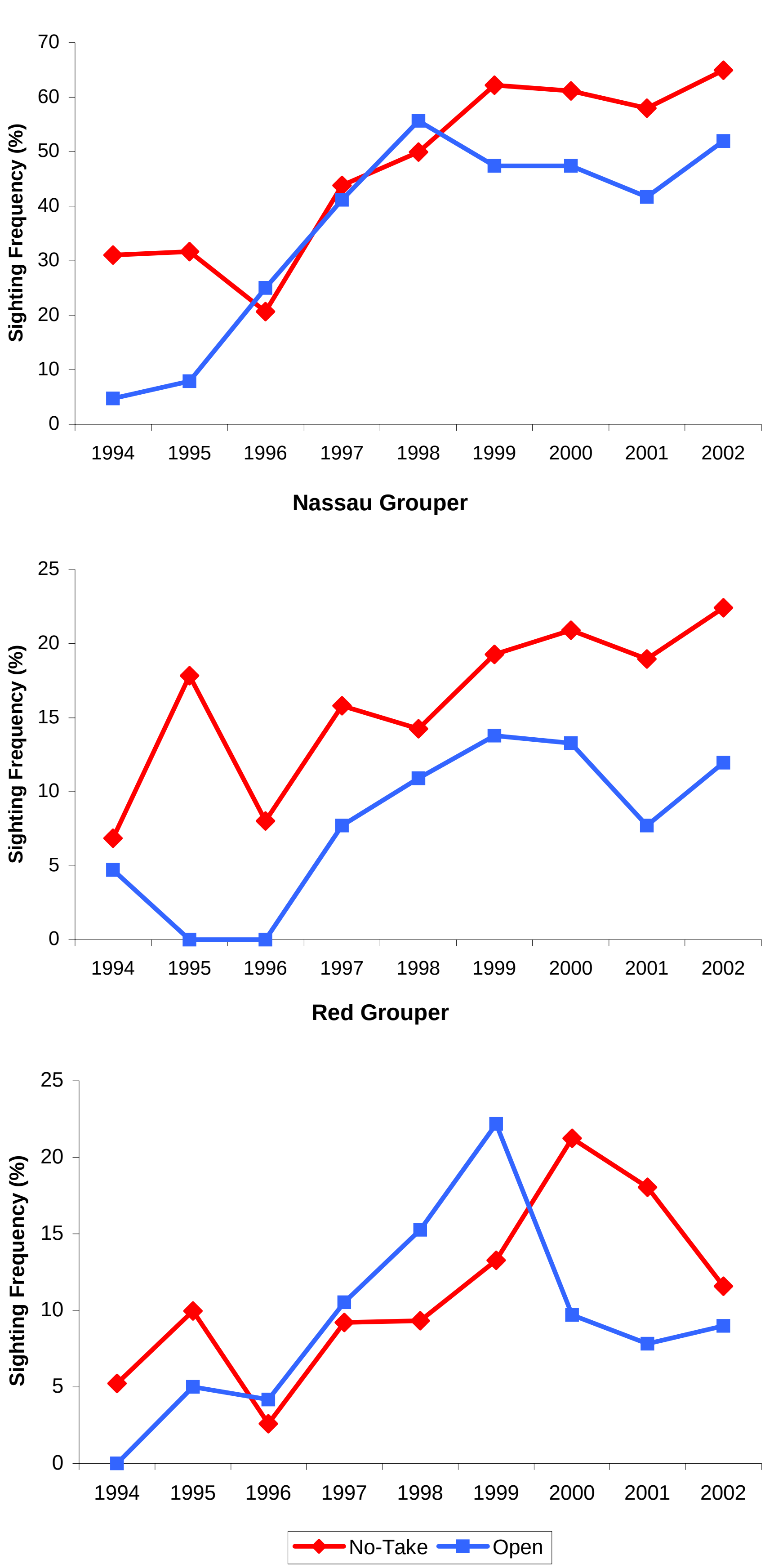


Figure 1. Sighting frequency over time for three species of grouper at 27 sites in the FKNMS; 16 FPMZs (implemented in 1997) and 11 reference sites.

Carnivore Abundance in the FKNMS

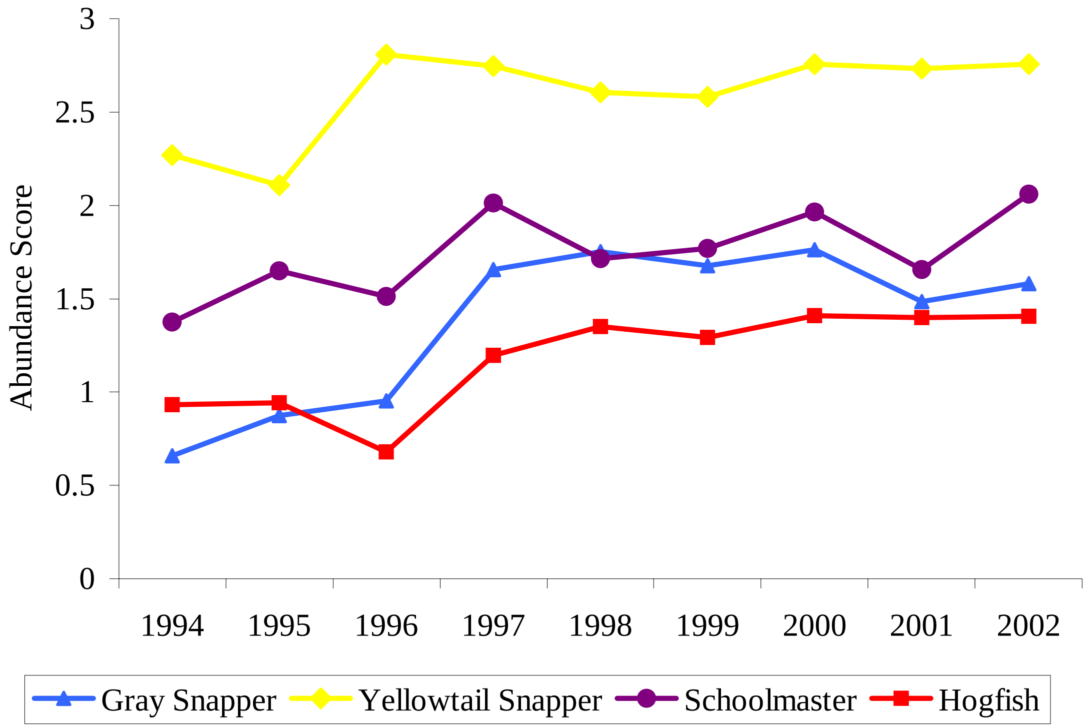


Figure 2. Average abundance over time of four carnivore species. Data are combined from 27 sites in the FKNMS; 16 FPMZs (implemented in 1997) and 11 reference sites.

Angelfish Abundance in the FKNMS

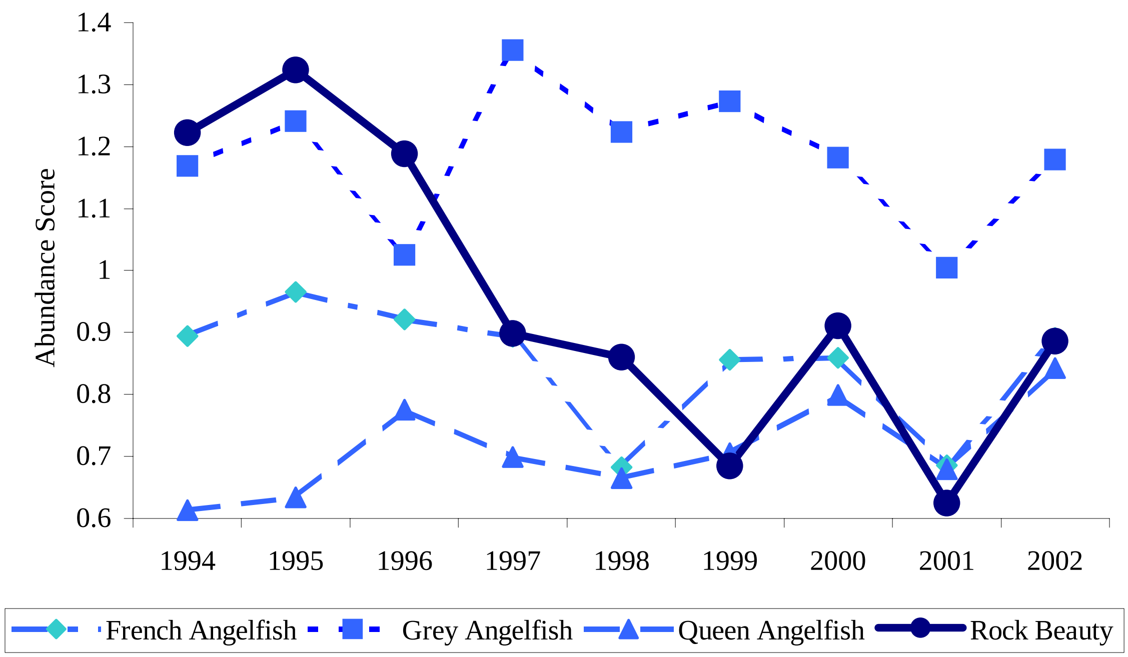


Figure 3. Abundance of four angelfish species at 27 sites in the FKNMS. Rock beauty, a species heavily targeted by marine life collectors for the aquarium industry, has exhibited significant declines between 1994 and 2002.

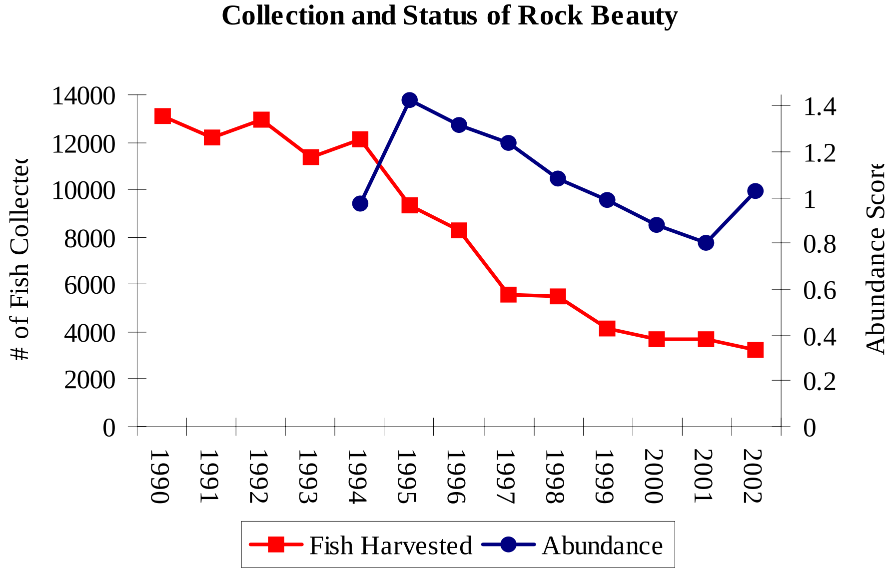


Figure 4. Rock beauty collection and population status. The number of fish collected is reported for all of Monroe County (FWC) and abundance score is based on REEF surveys conducted at all sites in the FKNMS.

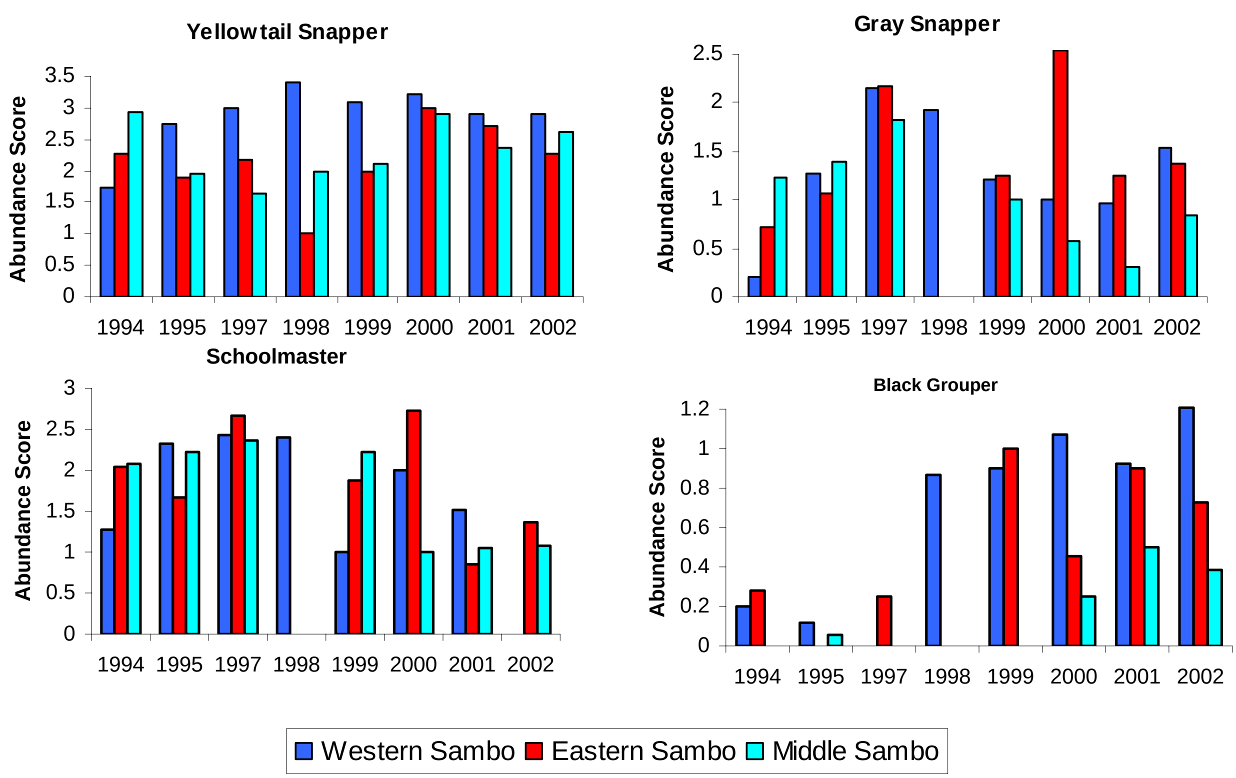


Figure 5. Yearly comparison in abundance of four fished species at the three Sambo sites. Western and Eastern Sambo were designated as no-take in 1997.

Monitoring Caribbean Spiny Lobsters in the Florida Keys National Marine Sanctuary, 1997-2002

Carrollyn Cox (Florida Fish and Wildlife Conservation Commission/Fish and Wildlife Research Institute, Marathon, FL)

Goals

We have monitored spiny lobsters in selected FPMZs of the Florida Keys National Marine Sanctuary (FKNMS) since they were closed to exploitation in July 1997. Our goal is to determine if the FPMZs are effective in protecting this highly mobile species from human exploitation by comparing the size and abundance of lobsters between fully protected and exploited areas.

Methods

We sampled 13 FPMZs and paired reference areas twice a year from 1997 until 2001. A closed-season census was performed at the end of the closed fishing season each July, and an open-season census was completed each September/October after several months of the lobster fishing season (August-April each year). Results of this work have been previously reported (http://floridakeys.noaa.gov/research_monitoring/). In 2002, we focused on the Western Sambo Ecological Reserve (WES), because it has shown signs of effectiveness in protecting spiny lobsters from fishing. We discontinued sampling at all other FPMZs except Looe Key SPA (LKS) because it has been a lobster reserve for more than 20 years, and Eastern Sambo Research Only Area (ESB) because lobsters have been very abundant there and it is close to WES. We also reduced our sampling to a single census at each site during July (closed fishing season). In all years, sampling was stratified by habitat (fore reef, back reef, and offshore patch reef) in WES, and three sub-samples were taken within each habitat. One sample was taken in forereef habitat at the other sites. Samples consisted of a 60-minute timed search during which we counted and attempted to catch all lobsters observed. Size, sex, molt stage, reproductive state (females), den number, and depth were recorded for each lobster encountered. Data from LKS, ESB, and WES were treated separately and compared with data from their respective exploited reference areas.

Findings to Date

In 1997, there was little difference between the number of lobsters inside FPMZs and reference areas, but after five years of protection we found almost twice as many lobsters inside the three FPMZs as outside (Fig. 1). The total number of lobsters observed in FPMZs varied among years with a high in 1999 following a low in 1998. There usually were more lobsters in FPMZs than in reference areas during the closed fishing season, and the number of lobsters observed in reference areas always decreased dramatically during the fishing season. We found more lobsters in FPMZs during the fishing season than during the closed season in three of the five years for which we have data (Fig. 1).

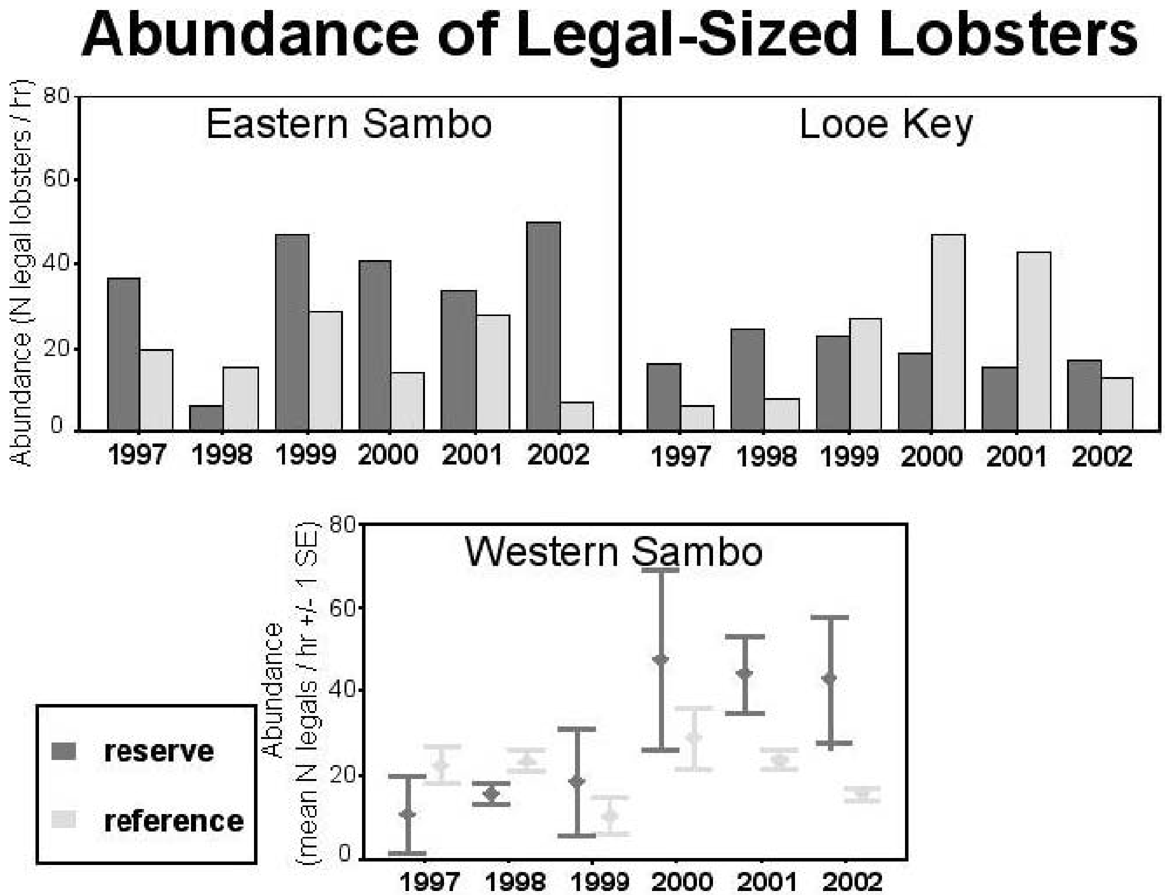


Figure 1. Total number of lobsters observed at Western Sambo Ecological Reserve, Eastern Sambo Research Only Area, Looe Key SPA, and adjacent reference areas during closed and open fishing seasons, 1997-2002. The FPMZs were implemented in 1997.

Legal-sized lobsters were very abundant on the fore reef at WES and ESB. Since 1999, abundance of legal-sized lobsters (n legal lobsters observed/hr) has always been greater in those FPMZs than in their reference areas (Fig. 2). Abundance of legal-sized lobsters at Looe Key SPA was higher on average than at many of the other FPMZs we sampled from 1997 until 2001. However, legal-sized lobster abundance was not higher in Looe Key SPA than in its reference area (Fig. 2) despite the fact that Looe Key has been a lobster reserve since 1981.

Efficacy of FPMZs will not be observed as absolute increases in lobster abundance inside the protected areas because lobster population abundance is cyclical. Rather, the important measure of abundance is increased abundance inside FPMZs relative to reference areas. We have observed this relative increase in abundance of legal-sized lobsters on the fore reef at WES (Fig. 3). There was no such trend observable at LKS, probably because the protected area is small compared to the home range of lobsters denning inside it. Though ESB is also small, there is a trend of increasing relative abundance of lobsters there that may be attributed in part to the proximity of the large Western Sambo Ecological Reserve.

In general, mean lobster size was below the legal limit (76 mm carapace length [CL]) in FPMZs and reference areas in 1997. LKS, ESB, and its reference area were notable exceptions with mean lobster size larger than the legal limit (Fig. 4). Since implementation of marine zoning in 1997, mean lobster size in FPMZs has been larger than legal size and comparatively larger than in reference areas. There were no differences in size of legal lobsters between Looe Key SPA and its reference area despite the longevity of protection at Looe Key. However, there has been a significant increase in the size of legal-sized lobsters in the large Western Sambo Ecological Reserve (Fig. 4). Mean size of male lobsters on offshore patch reefs in WES has increased 10 mm in five years (Fig. 5). Abundance of very large lobsters (≥ 100 mm CL) increased in WES relative to its reference area with males becoming larger as well as more abundant (Fig. 6).

Our data indicate that a resident population of spiny lobsters is becoming established within Western Sambo Ecological Reserve. The expansion of lobster size range in the WES suggests that some lobsters remain in the ecological reserve for an extended period. Habitat for all life stages of spiny lobsters is protected within it. Once adults establish residence, the ecological reserve is sufficiently large to protect a portion of the population as it travels to foraging grounds and between winter dens and spring spawning habitat.

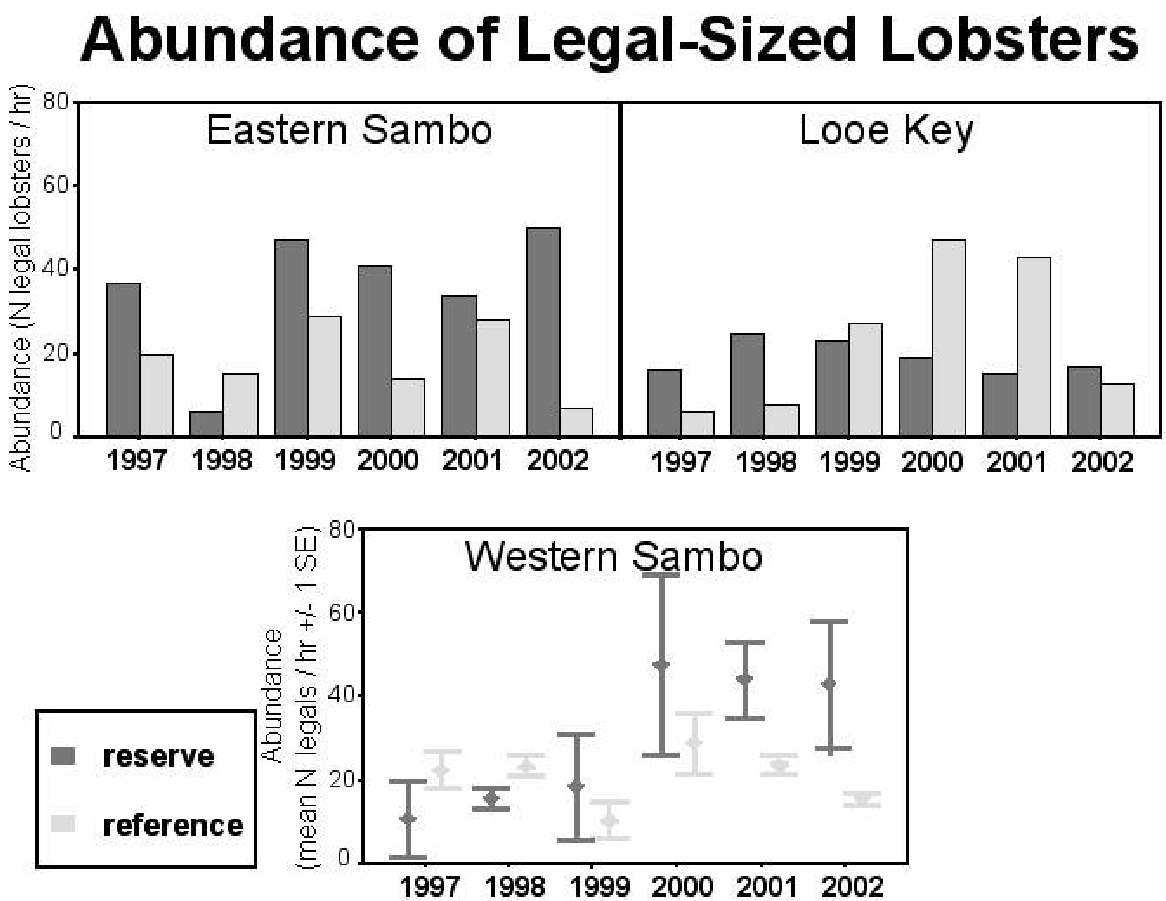


Figure 2. Abundance of legal-sized lobsters on the fore reef in FKNMS FPMZs and corresponding reference areas during the closed fishing season, 1997-2002.

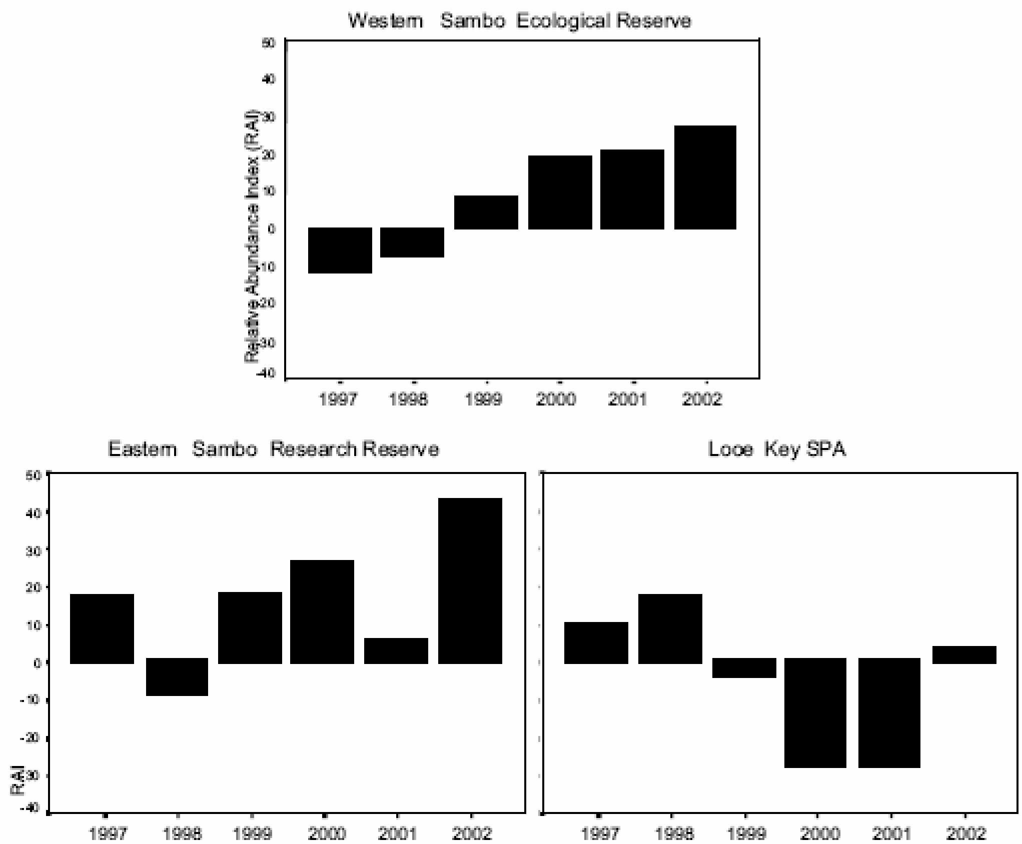


Figure 3. Relative abundance index (RAI) of legal-sized lobsters on fore reef habitat during the closed fishing season, 1997-2002. RAI = [mean abundance in FPMZ] – [mean abundance in reference area].

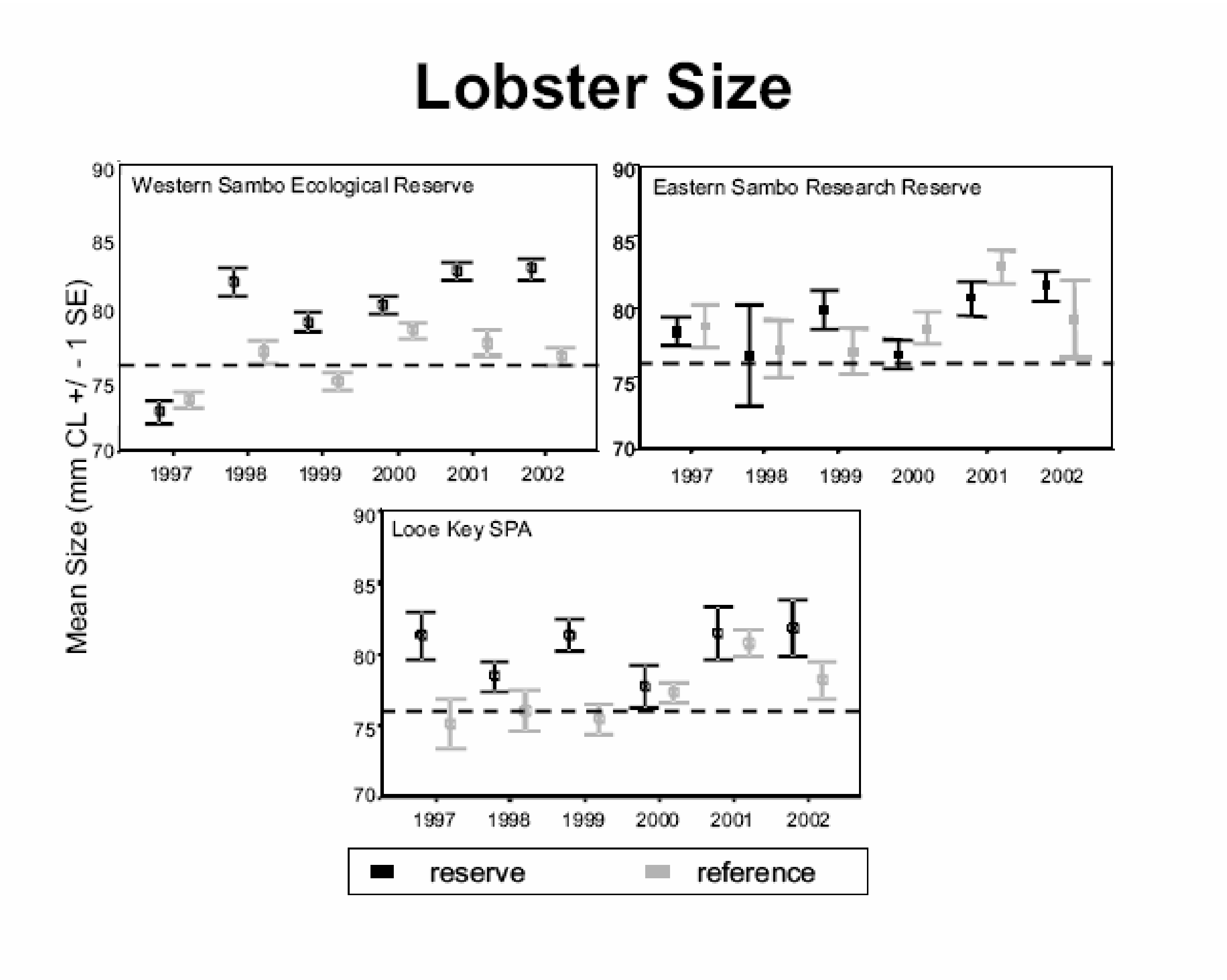


Figure 4. Size of spiny lobsters in FKNMS FPMZs during the closed fishing season, 1997-2002. Dashed line represents the minimum legal size (76 mm CL). Data for Western Sambo Ecological Reserve and its reference area include lobsters from forereef, backreef, and offshore patch reef habitats. Looe Key SPA and Eastern Sambo R-OA observations were made on the fore reef only.

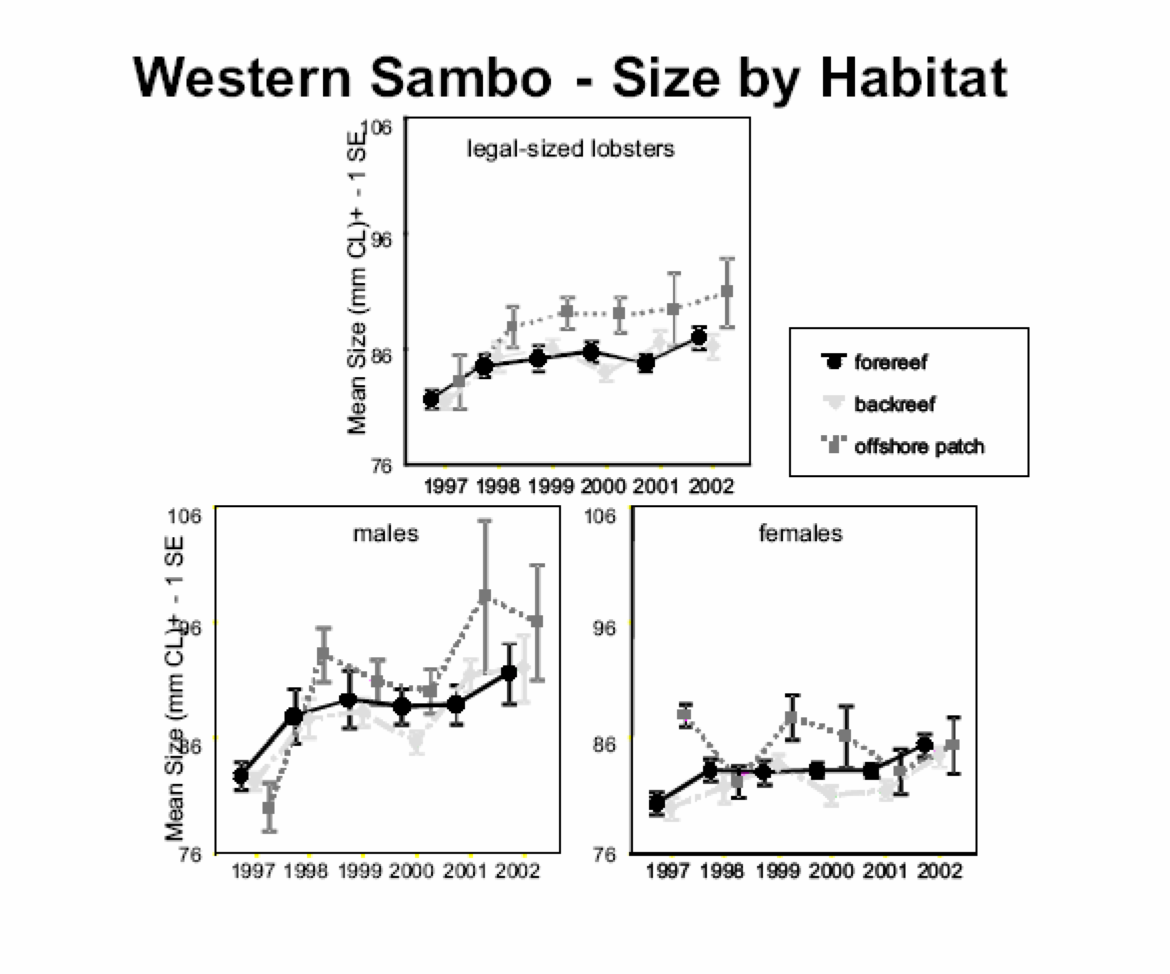


Figure 5. Mean size of male and female spiny lobster in Western Sambo Ecological Reserve by habitat during the closed fishing season, 1997-2002.

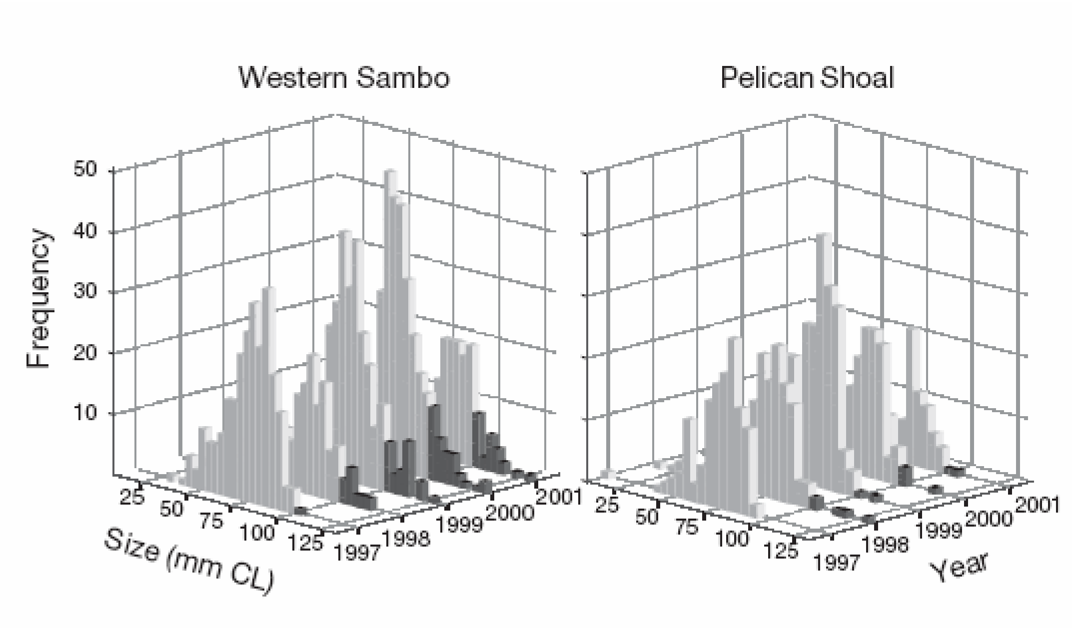


Figure 6. Size frequency of male spiny lobsters in Western Sambo Ecological Reserve and Pelican Shoal (reference area). Dark bars at 100-mm CL shown for comparison.

Queen Conch Monitoring

Robert A. Glazer and Gabriel A. Delgado (Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Marathon, FL)

Goal

Effective evaluation of the Florida Keys National Marine Sanctuary marine zoning plan requires a well-conceived monitoring study to compare resources in fully protected marine zones (FPMZs) and reference areas. The goal of this project is to determine effects of FPMZs on the density, abundance, and area occupied by queen conch in the FKNMS. We surveyed queen conch aggregations by conducting belt-transect surveys at offshore reef aggregations within Sanctuary Preservation Areas (SPAs) and Special Use (Research Only) Areas. Additionally, reef areas without protective status were surveyed (reference areas). Aggregations were surveyed for juvenile and adult density, abundance, and overall aggregation size in order to evaluate patterns of abundance and recruitment. The results from these surveys will also be used to evaluate the effectiveness of the marine reserve concept as a means for protecting and restoring the Florida conch population to historic numbers. This is the sixth annual report on the results of these surveys.

Methods

Sampling occurred between May and October 2002 in order to ensure that the surveys were conducted during the period of maximal density associated with spawning. The surveys were conducted at FPMZ reef locations as well as reefs without restrictions (i.e., reference areas; Fig. 1). In many cases, the only conch aggregations at FPMZ reefs were located outside protected area boundaries. We defined aggregations as discernible clusters of adult and/or juvenile conch.

An initial survey of each site was made to determine the presence of conch, the approximate size of the aggregation, and an apical edge beyond which conch were infrequent or not observed. If a conch aggregation was estimated to be greater than approximately 100 m in length, a 100-m fiberglass tape (primary tape) was affixed at an apex and was deployed along the margin of the aggregation. Five secondary tapes (i.e., belts) were laid perpendicular to the primary tape at random intervals along the primary tape. Divers then recorded all conch within 1 m of each side of the belts. Densities were determined by dividing the number of conch counted by the area surveyed. Regional (i.e., Upper, Middle, and Lower Keys) and overall (i.e., Keys-wide) densities were calculated using all individuals sampled in the year divided by the total area sampled. Aggregations were mapped to determine overall abundance; we used GPS data to determine the periphery of aggregations. The area encompassed by each aggregation was estimated using ArcView GIS software.

In areas where conch were very sparse, direct counts were made of individuals and belts were not conducted. The counts of individual conch were used to estimate abundance for the aggregation, region, and overall Keys. However, these observations were not included in the subsequent calculations of regional and overall density because densities were not measured.

We examined the overall aggregation area, adult abundance, juvenile abundance, adult density, and juvenile density as a means to evaluate changes in FPMZs and reference areas. Two-way ANOVAs were used to compare FPMZs and reference areas over the period of record (i.e., 1997 to 2002). In addition, one-way ANOVAs were used to determine if there were differences in aggregation area, adult abundance, juvenile abundance, adult density, and juvenile density among regions of the Florida Keys.

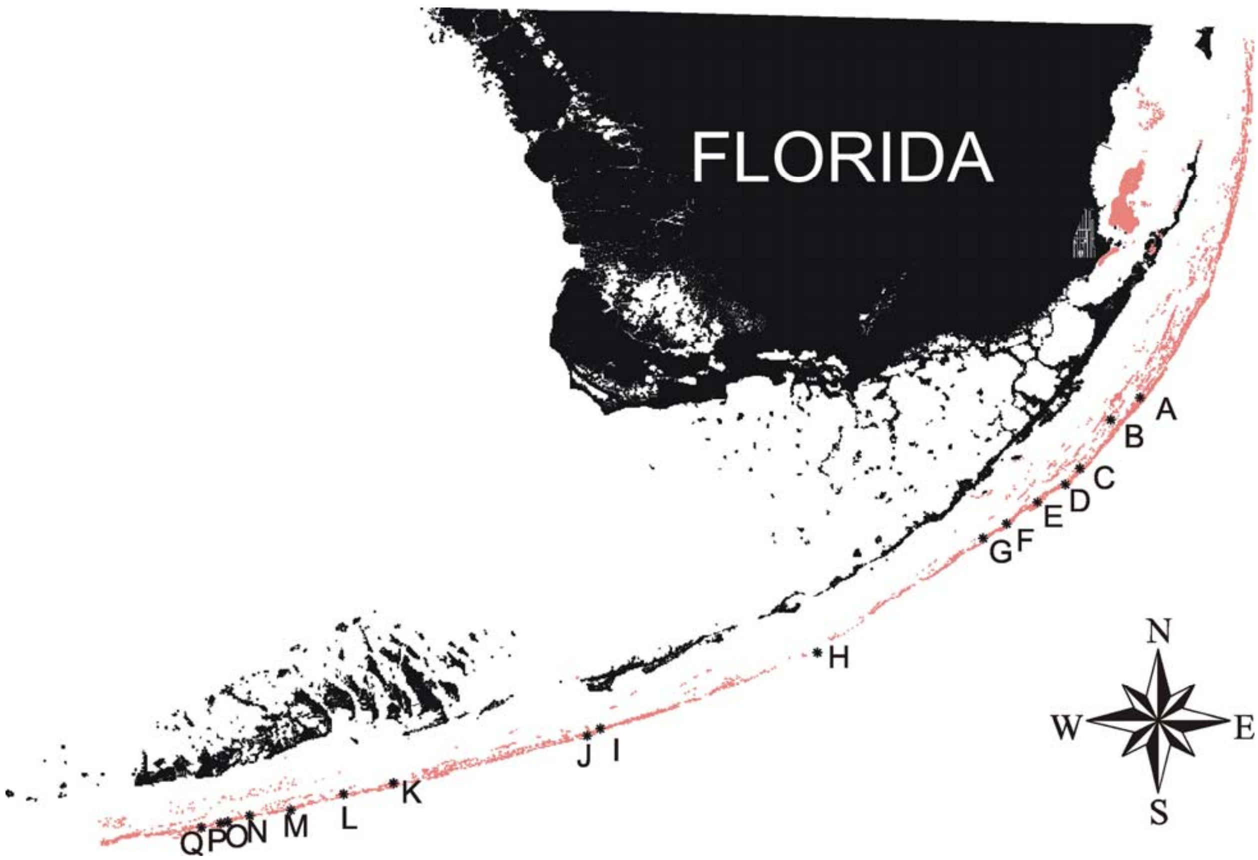


Figure 1. Sampling sites for queen conch monitoring project for 2002. The belt-transect sites included: (A) The Elbow SPA, (B) Grecian Rocks SPA, (C) French Reef SPA, (D) Sand Reef Ref., (E) Molasses Reef SPA, (F) Pickles Reef Ref., (G) Conch Reef SPA, (H) Alligator Reef SPA, (I) Delta Shoals Ref., (J) Sombrero Reef SPA, (K) Looe Key SPA, (L) American Shoal Ref., (M) Pelican Shoal Ref., (N) Eastern Sambo R-OA, (O) Middle Sambo Ref., (P) Western Sambo ER, and (Q) Eastern Dry Rocks SPA.

Findings to Date

A total of 27 aggregations were surveyed at 17 sites (Fig. 1). Densities were measured at 20 conch aggregations and direct counts were conducted at the other seven aggregations. In many cases, conch aggregations were located outside the boundaries of FPMZs.

Juvenile densities ranged from 0.000 individuals•m^{-2} at an adult-only aggregation at Conch Reef to a maximum of 0.649 individuals•m^{-2} at the Elbow (Tables 1-3). Excluding Conch Reef, where no juveniles were found within the belts, the lowest density of juveniles at an aggregation was at Eastern Dry Rocks where 0.001 individuals•m^{-2} were observed (Tables 1-3). The highest abundance of juvenile conch by far was observed at the Elbow in the Upper Keys; approximately 12,102 juveniles were estimated to be present (Table 1). This one site alone had over a third of the total number of juveniles seen in the Florida Keys (Tables 1 and 4).

Table 1. Results of queen conch belt-transect surveys conducted in the Upper Keys at the beginning of the study (1997) and in 2002. Densities are reported in individuals•m^{-2}. Areas are for areas encompassed by the aggregations and are reported in m^2. The mean values reported for overall juvenile and adult densities were derived from the entire data set and not by averaging the mean densities of each aggregation.

Upper Keys										
SPA										
Site	Juv Abund (1997)	Juv Abund (2002)	Juv Density (1997)	Juv Density (2002)	Adult Abund (1997)	Adult Abund (2002)	Adult Density (1997)	Adult Density (2002)	Area (1997)	Area (2002)
Carysfort Reef	0	-	0.000	-	0	-	0.000	-	0	-
The Elbow	3,373	12,102	0.062	0.649	1,214	771	0.022	0.041	54,526	18,654
Key Largo Dry Rocks	0	-	0.000	-	0	-	-	-	0	-
Grecian Rocks	472	1,910	0.063	0.135	236	1,815	0.032	0.128	7,445	14,136
French Reef	56	10	0.003	-	992	55	0.054	-	18,422	-
Molasses Reef	130	1,235	0.006	0.074	2,152	1,407	0.105	0.084	20,480	16,732
Conch Reef	72	4	0.006	0.000	350	606	0.029	0.095	11,881	6,159
Mean			0.028	0.189			0.048	0.080		
Total	4,103	15,261			4,944	4,654			112,754	55,681
Reference										
Pickles	0	76	0.000	0.008	576	645	0.073	0.071	7,851	9,078
Mean			0.000	0.008			0.073	0.071		
Total	0	76			576	645			7,851	9,078
Overall - Upper Keys										
Mean			0.031	0.144			0.046	0.078		
Total	4,103	15,337			5,520	5,299			120,605	64,759

The Upper Keys had the highest juvenile conch densities with 0.144 juveniles•m^{-2} (Table 1). The Middle Keys had similar juvenile densities with 0.135 juveniles•m^{-2} (Table 2). The Lower Keys had the lowest densities (0.045 juveniles•m^{-2}, Table 3). Estimated regional abundance for juvenile conch ranged from approximately 15,337 individuals in the Upper Keys to 6,400 in the

Middle Keys (Tables 1 & 2). Like the Upper Keys, most of the juveniles in the Middle Keys were located at one site, Delta Shoal (Table 2). The Lower Keys had an estimated 12,322 juveniles, spread fairly evenly among seven sites (Table 3).

Table 2. Results of queen conch belt-transect surveys conducted in the Middle Keys at the beginning of the study (1997) and in 2002. Densities are reported in individuals•m^{-2}. Areas are for areas encompassed by the aggregations and are reported in m^2. The mean values reported for overall juvenile and adult densities were derived from the entire data set and not by averaging the mean densities of each aggregation.

Middle Keys										
SPA										
Site	Juv Abund (1997)	Juv Abund (2002)	Juv Density (1997)	Juv Density (2002)	Adult Abund (1997)	Adult Abund (2002)	Adult Density (1997)	Adult Density (2002)	Area (1997)	Area (2002)
Alligator Reef	48	107	0.010	-	86	59	0.018	-	4,791	-
Sombrero Key	4	870	-	0.045	0	659	-	0.034	-	19,384
Mean			0.01	0.045			0.018	0.034		
Total	52	977			86	718			4,791	19,384
Reference										
Delta Shoal	33	5,423	0.012	0.226	77	884	0.028	0.037	2,699	23,992
Mean			0.012	0.226			0.028	0.037		
Total	33	5,423			77	884			2,699	23,992
Overall - Mid Keys										
Mean			0.011	0.135			0.021	0.035		
Total	85	6,400			163	1,602			7,490	43,376

Adult conch density was highest at Eastern Sambo (0.129 adults•m^{-2}, Table 3) and was lowest at Sombrero Reef (0.034 adults•m^{-2}, Table 2). The highest estimated abundance was at Eastern Sambo with an estimated 12,560 adults (Table 3), representing over 40% of the total number of adult conch found in the Florida Keys. Of the sites where adult conch were surveyed within belt transects, Conch Reef had the lowest abundance with an estimated 606 conch present (Table 1). The region with the most adults by far was the Lower Keys (approximately 23,640) followed by the Upper Keys (approximately 5,299) and the Middle Keys (approximately 1,602) (Tables 1-3).

Table 3. Results of queen conch belt-transect surveys conducted in the Lower Keys at the beginning of the study (1997) and in 2002. Densities are reported in individuals•m^{-2}. Areas are for areas encompassed by the aggregations and are reported in m^2. The mean values reported for overall juvenile and adult densities were derived from the entire data set and not by averaging the mean densities of each aggregation.

Lower Keys										
SPA										
Site	Juv Abund (1997)	Juv Abund (2002)	Juv Density (1997)	Juv Density (2002)	Adult Abund (1997)	Adult Abund (2002)	Adult Density (1997)	Adult Density (2002)	Area (1997)	Area (2002)
Looe Key	1,349	2,484	0.021	0.063	2,501	939	0.049	0.042	56,451	29,076
Eastern Sambo	773	4,230	0.018	0.047	4,348	12,560	0.101	0.129	42,903	91,134
Western Sambo	411	1,190	0.008	0.026	2,765	2,285	0.055	0.049	50,252	46,460
Eastern Dry Rocks	2	19	-	0.001	21	991	-	0.062	-	15,967
Mean			0.016	0.042			0.066	0.092		
Total	2,535	7,923			9,635	16,775			149,606	182,637
Reference										
American Shoal	69	121	0.007	0.012	617	634	0.062	0.061	10,010	10,466
Pelican Shoal	2,455	3,399	0.061	0.075	944	1,835	0.023	0.047	40,533	48,005
Middle Sambo	767	879	0.014	0.035	3,987	4,396	0.072	0.174	55,370	25,277
Mean			0.030	0.051			0.054	0.078		
Total	3,291	4,399			5,548	6,865			105,913	83,748
Overall - Lower Keys										
Mean			0.023	0.045			0.060	0.088		
Total	5,826	12,322			15,183	23,640			255,519	266,385

The four aggregations at Eastern Sambo covered the most area; the extent of these aggregations was estimated to be 91,134 m^2 (Table 3). The three aggregations at Pelican Shoal encompassed 48,005 m^2 (Table 3). The single largest aggregation was at Western Sambo (46,460 m^2, Table 3). The Lower Keys region had the most area encompassed by conch aggregations (266,385 m^2, Table 3).

We estimated that there were approximately 30,541 adult conch within the offshore aggregations during 2002 (Table 4). In 1997, we estimated that there were approximately 20,866 adult conch (Table 4). We estimated that there were approximately 34,059 juveniles in the study area in 2002 compared with 10,014 in 1997 (Table 4).

Table 4. Summary of queen conch belt-transect surveys conducted in the Florida Keys in 2002.

	Juv Abund (1997)	Juv Abund (2002)	Juv Density (1997)	Juv Density (2002)	Adult Abund (1997)	Adult Abund (2002)	Adult Density (1997)	Adult Density (2002)	Area (1997)	Area (2002)
Mean			0.025	0.074			0.055	0.080		
Total	10,014	34,059			20,866	30,541			383,614	374,520

Two-way ANOVAs indicated that there were no significant differences between FPMZs and reference areas over the period of record for adult density (two-way ANOVA: $F_{\text{btwn SPA/reference}}$ = 0.08, P = 0.790; $F_{\text{among years}}$ = 0.48, P = 0.781), adult abundance (two-way ANOVA: $F_{\text{btwn SPA/reference}}$ = 2.91, P = 0.114; **$F_{\text{among years}}$ = 7.16, P = 0.025**), juvenile density (two-way ANOVA: $F_{\text{btwn SPA/reference}}$ = 1.66, P = 0.241; **$F_{\text{among years}}$ = 20.01, P = 0.003**), juvenile abundance (two-way ANOVA: $F_{\text{btwn SPA/reference}}$ = 0.02, P = 0.900; **$F_{\text{among years}}$ = 12.50, P = 0.007**), and aggregation area (two-way ANOVA: $F_{\text{btwn SPA/reference}}$ = 2.99, P = 0.132; **$F_{\text{among years}}$ = 11.14, P = 0.010**) (Fig. 2-4). However, there were significant differences in adult abundance, juvenile density, juvenile abundance, and aggregation area over time (indicated in **bold** above) (Fig. 2-4). None of the ANOVAs had any significant interactions.

A comparison among regions during 2002 indicated that there were no significant differences in adult density (one-way ANOVA: $F_{\text{among regions}}$ = 1.05, P = 0.381), adult abundance (one-way ANOVA: $F_{\text{among regions}}$ = 0.90, P = 0.427), juvenile density (one-way ANOVA: $F_{\text{among regions}}$ = 1.00, P = 0.401), juvenile abundance (one-way ANOVA: $F_{\text{among regions}}$ = 0.24, P = 0.790), and aggregation area (one-way ANOVA: $F_{\text{among regions}}$ = 2.27, P = 0.150) (Fig. 5-7).

Discussion

The results of the sixth year of queen conch monitoring support those of earlier years: conch are recovering, albeit slowly, and aggregations are distributed in well-defined clusters that, in general, are not entirely encompassed by FPMZ boundaries. Additionally, many sites now have more than one aggregation, notably Eastern Sambo and Pelican Shoal. Conch are also distributed in marked regional patterns. For example, the Lower Keys region from Looe Key to Eastern Dry Rocks is a complex containing approximately 23,000 of the 30,000 adults located throughout the Keys. There were relatively few adult conch in the Middle Keys; however, the approximately 1,600 adults surveyed were a dramatic increase for the region. This increase was due to a large cohort of juveniles that recruited in 2000 and 2001 (Fig. 3) and have begun to reach maturity.

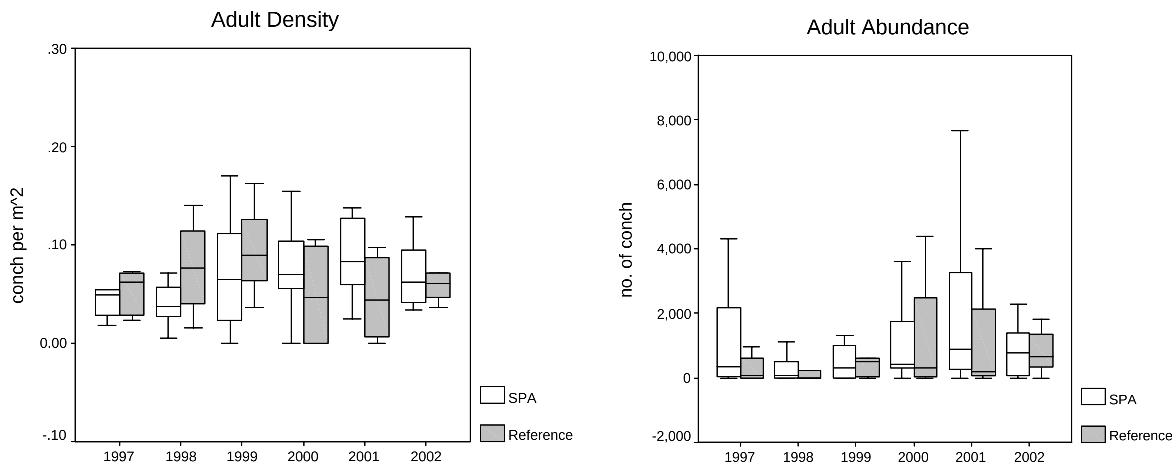


Figure 2. Box plots of the density and abundance of adult queen conch by protective status (i.e., SPA and reference areas) in the Florida Keys. The box represents the 25th and 75th percentiles. The horizontal line within the box indicates the median. The error bars represent the 10th and 90th percentiles.

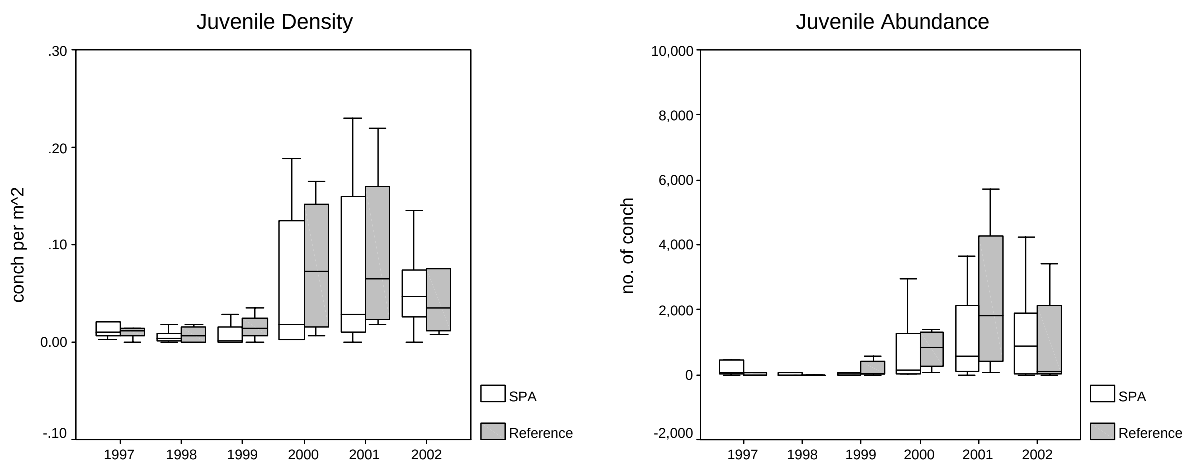


Figure 3. Box plots of the density and abundance of juvenile queen conch by protective status (i.e., SPA and reference areas) in the Florida Keys. The box represents the 25th and 75th percentiles. The horizontal line within the box indicates the median. The error bars represent the 10th and 90th percentiles.

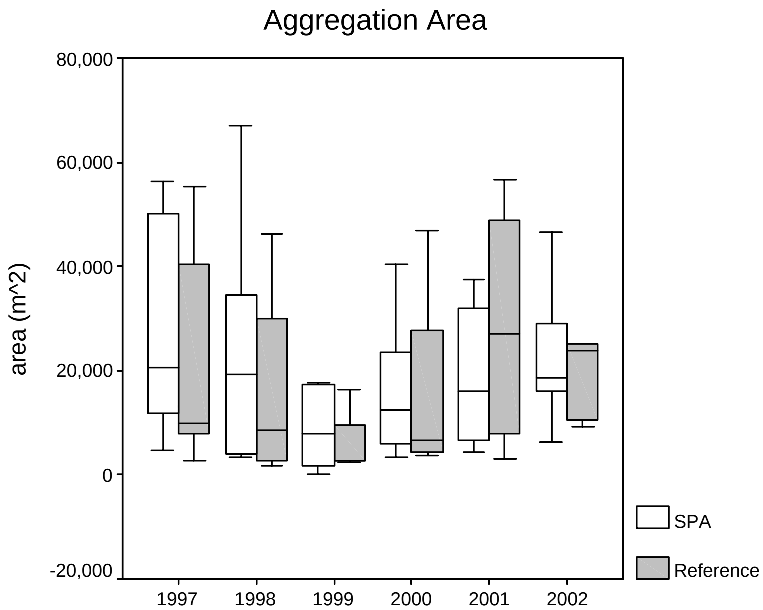


Figure 4. Box plot of queen conch aggregation area by protective status (i.e., SPA and reference areas) in the Florida Keys. The box represents the 25th and 75th percentiles. The horizontal line within the box indicates the median. The error bars represent the 10th and 90th percentiles.

We expect that the number of adult conch in the Middle Keys will continue to increase next year. Overall, adult abundance has increased from 1997 to 2002 while density has remained relatively stable during recent years (Fig. 2).

There was a large amount of recruitment in 2002 - not as much as in 2000 or 2001, but noticeably higher than from 1997 through 1999 (Fig. 3). In the Upper Keys, juvenile abundance increased from about 10,000 in 2001 to 15,000 in 2002. In the Middle Keys, juvenile abundance has remained fairly even over the last two years. In the Lower Keys, juvenile abundance has also increased to nearly match the number seen in the Upper Keys. This was due to the identification of new conch aggregations. We expect that as long as recruitment remains high and the population continues to increase, we will continue to find new aggregations next year as conch move into previously unoccupied areas.

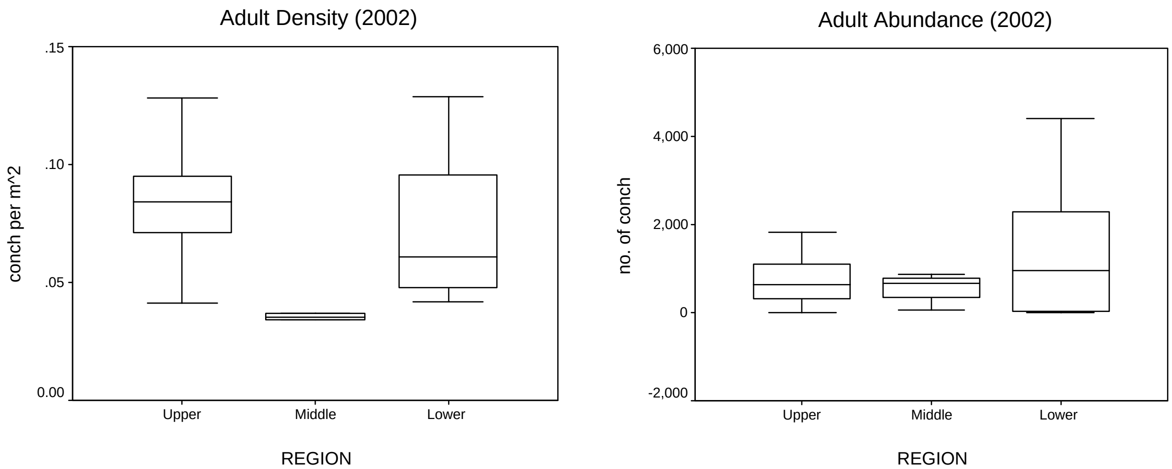


Figure 5. Box plots of the density and abundance of adult queen conch in 2002 by region in the Florida Keys. The box represents the 25th and 75th percentiles. The horizontal line within the box indicates the median. The error bars represent the 10th and 90th percentiles.

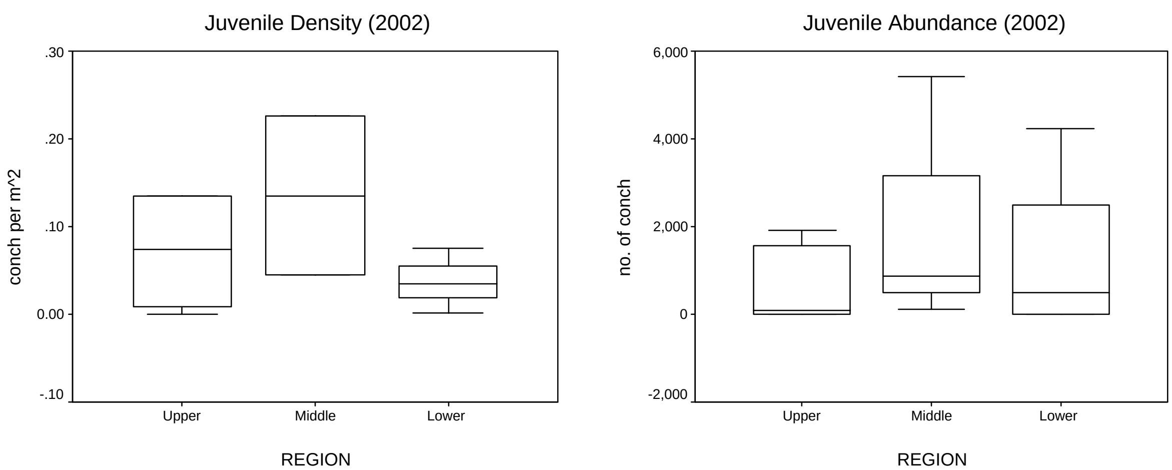


Figure 6. Box plots of the density and abundance of juvenile queen conch in 2002 by region in the Florida Keys. The box represents the 25th and 75th percentiles. The horizontal line within the box indicates the median. The error bars represent the 10th and 90th percentiles.

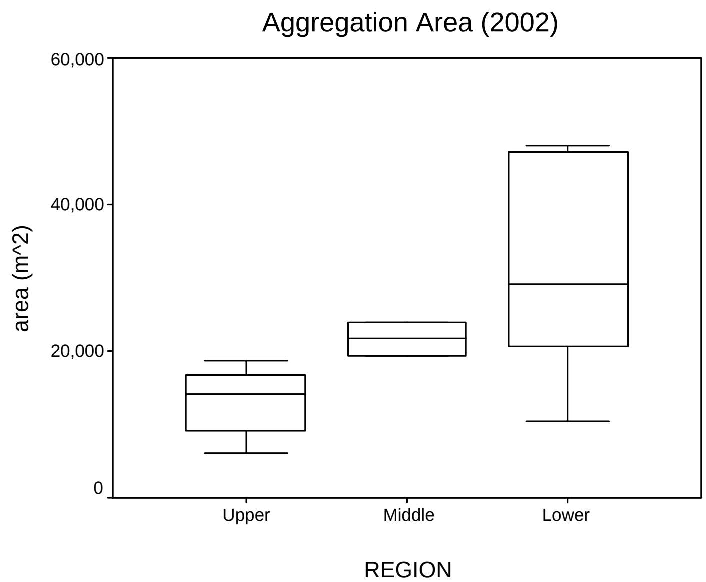


Figure 7. Box plot of queen conch aggregation area in 2002 by region in the Florida Keys. The box represents the 25th and 75th percentiles. The horizontal line within the box indicates the median. The error bars represent the 10th and 90th percentiles.

Socioeconomic Research and Monitoring Program

Importance and Satisfaction Ratings, A Five-Year Comparison (1995-96 to 2000-01)

Vernon R. (Bob) Leeworthy, Peter C. Wiley, and Justin Hospital (NOAA, National Ocean Service, Office of Management and Budget, Special Projects Division, Silver Spring, MD)

Goals

The goals of this project are to monitor and assess knowledge, attitudes, and perceptions of Sanctuary management strategies and regulations, specifically, to monitor and assess perceptions of the conditions of 25 natural resource attributes, facilities, and services by both residents of Monroe County and visitors to Monroe County and the FKNMS.

Methods

Five-year comparisons of mean importance and satisfaction scores were conducted for 25 natural resource attributes, facilities, and services (see Leeworthy et al. 2004). Baseline measurements were obtained in 1995-96 for both residents of Monroe County and visitors to Monroe County-FKNMS. This was done in the project entitled "Linking the Economy and the Environment of the Florida Keys/Florida Bay." The 1995-96 project serves as the baseline for the Recreation and Tourist component of the Socioeconomic Research and Monitoring Program for the FKNMS (for background description of the program and reports go to: http://marineeconomics.noaa.gov).

In the 2000-01 reef-user study, we were not able to replicate the Importance-Satisfaction ratings for all residents and visitors of Monroe County as was done in 1995-96. Instead we were able to take advantage of a multiple agency partnership to conduct the "Socioeconomic Study of Reefs in Southeast Florida, 2000-2001" (see Johns et al. 2003a for main report and Johns et al. 2003b for the technical appendix). This was a study of artificial and natural reefs off Palm Beach, Broward, Miami-Dade, and Monroe Counties. Through the Socioeconomic Research and Monitoring Program for the FKNMS, we were able to add several extra modules of questions to address issues in the FKNMS. The scope was limited to residents and visitors that engaged in boating activities and used either an artificial or natural reef. We were able to go back to the 1995-96 baseline databases and select those residents and visitors that engaged in boating activities so we could make five-year comparisons of mean importance and satisfaction scores for this group. Future plans call for a more complete replication of the 1995-96 study. This is tentatively planned for 2005-06.

Another important issue to note is that the same samples of resident and visitor populations were not surveyed in each iteration of the survey. In other words the respondents to the 1995-96 survey were not the same respondents to the 2000-01 survey. The implications of this include the potential for other factors, besides changes in the condition of the attributes, explaining the changes in ratings between time periods. These include changes in the demographic makeup and varying preferences of the 2000-01 sample compared to the 1995-96 sample. We account for this by also segmenting our samples by level of experience. Experienced users were defined as those with five or more years of experience.

For many years, the U.S. Forest Service and many other federal, state, and local agencies that manage parks and/or other natural resources have used the National Satisfaction Index (NSI) for measuring visitor satisfaction. Satisfaction is a complex feature of the recreation/tourist experience and most researchers now agree that “Importance-Performance” or “Importance-Satisfaction” is a much more complete measure and provides a much simpler interpretation than the NSI. First described in the marketing literature by Martilla and James (1977), it has been described and/or used in such studies as Guadagnolo (1985), Richardson (1987), Hollenhorst et al. (1992), and Leeworthy and Wiley (1996, 1997).

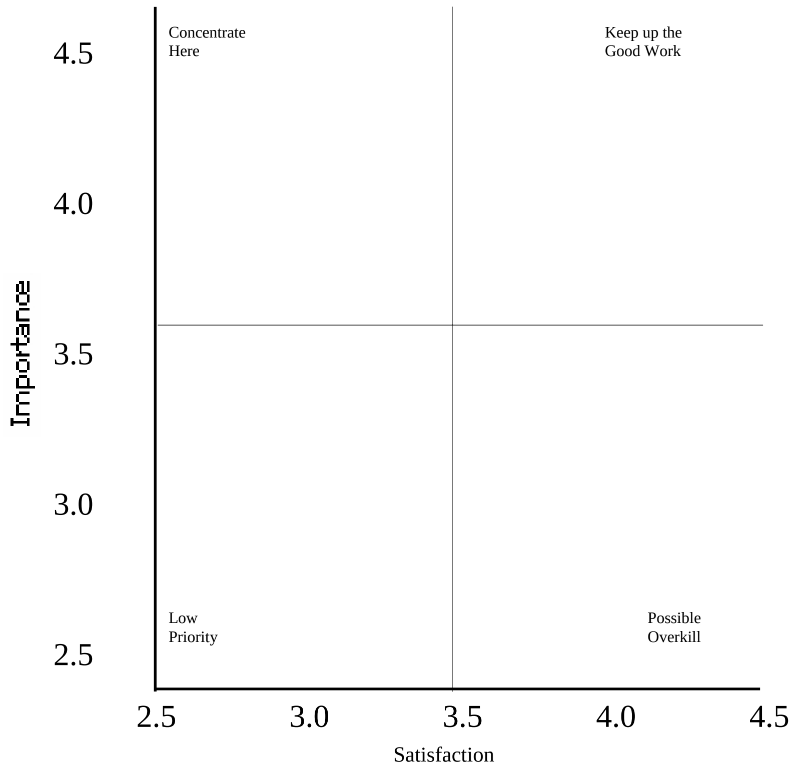
The satisfaction questionnaire was divided into two sections to obtain the necessary information for the importance-satisfaction analysis. The first section asked the respondent to read each statement and rate the importance of each of the 25 items as it contributes to an ideal recreation/tourist setting for the activities in which they participated in the FKNMS. Each item was rated or scored on a one to five scale with one (1) meaning “Not Important” and five (5) meaning “Extremely Important.” The respondent was also given the choices of answering “Not Applicable” or “Don’t Know.” The second section asked the respondent to consider the same list of items they just rated for importance and to rate them for how satisfied they were with each item at the places where they did their activities in the FKNMS. Again, a five-point scale was used with one (1) meaning “Terrible” and a score of five (5) meaning “Delighted.” Respondents were also given the choices of answering either “Not Applicable” or “Don’t Know.”

There were 275 respondents in the 2000-01 visitors’ survey and 917 respondents in the 1995-96 visitors’ survey who had usable importance-satisfaction responses. There were 609 respondents in the 2000-01 resident survey and 455 respondents in the 1995-96 resident survey who had usable importance-satisfaction responses. In the analyses, these samples were treated as separate, independent samples.

Two-sample t-tests comparing mean importance and satisfaction scores were used with the 0.05 level of significance as the cut-off point for significance (95% confidence level). The tests were done for comparisons between years (1995-96 and 2000-01), and for 2000-01 between experienced and less-experienced users. Importance-satisfaction analysis was used for identifying key areas and priority areas of concern.

The most useful analytical framework provided in importance-satisfaction analysis is the four-quadrant presentation. The four quadrants are formed by first placing the importance measurement on the vertical axis and the satisfaction measurement on the horizontal axis (see Fig. 1). An additional vertical line is placed at the mean score for all 25 items on the satisfaction scale and an additional horizontal line is placed at the mean score for all 25 items on the importance scale. These two lines form a cross hair. The cross hair then separates the importance-satisfaction measurement area into four separate areas or quadrants. This allows for interpretation as to the “relative importance” and “relative satisfaction” of each item. That is, if everyone gave high scores to all items in the FKNMS, we would still be able to judge the relative importance and satisfaction and establish priorities.

Figure 1. Importance/Satisfaction Matrix



The use of the four quadrants provides a simple but easy-to-interpret summary of results. Scores falling in the upper left quadrant are relatively high on the importance scale and relatively low on the satisfaction scale. This quadrant is labeled "**Concentrate Here**." Scores falling in the upper right quadrant are relatively high on the importance scale and also relatively high on the satisfaction scale and are labeled "**Keep up the Good Work**." Scores falling in the lower left quadrant are relatively low on both the importance and satisfaction scale and are labeled "**Low Priority**." And, finally, scores in the lower right quadrant are relatively low on the importance scale but relatively high on the satisfaction scale and are labeled "**Possible Overkill**."

In general, the 25 items that residents and visitors were asked to rate are organized into four categories. In the survey, the order of the items was mixed. All of the items were assigned a letter (A through Y). Items A through G are labeled as "**Natural Resources**." These seven items are either natural resources or attributes of natural resources such as clear water. Items H through M are labeled as "**Natural Resource Facilities**." These six items are either facilities that provide access to natural resources or areas or features that provide public access to natural resources. Items N through V are labeled as "**Other Facilities**." These nine items are either facilities or features of facilities that are not directly related to natural resources but are indirectly related because they represent items associated with the general infrastructure of the area. Items W through Y are labeled as "**Services**." These three items are either services or features of a service provided to residents and visitors. We considered separate analyses for each group but rejected this approach in favor of establishing the relative importance of each item with respect to all items. The organization into four categories was done simply as an aid to those users who have responsibilities in separate areas.

Findings

Summary results of the statistical test for differences in mean importance and satisfaction scores for all 25 natural resource attributes, facilities, and services for both resident and visitor samples are presented in Table 1. In Table 2, the results for comparing differences between experienced and less-experienced users are given for 2000-01.

Visitors

Importance

- 2000-01 boating visitors had significantly higher importance scores than the 1995-96 sample for 20 out of 25 attributes.
- More-experienced visitors had higher importance scores than less-experienced visitors for 5 out of 25 attributes, and lower scores for 2 out of 25 attributes.

Satisfaction

- 2000-01 boating visitors had significantly lower satisfaction scores than 1995-96 boating visitors for 24 out of 25 attributes.
- More-experienced visitors had lower satisfaction scores than less-experienced visitors for 18 of 25 attributes.

Residents

Importance

- 2000-01 boating residents had significantly lower importance score than the 1995-96 sample for 19 out of 25 attributes and a significantly higher importance score for one attribute.
- More-experienced residents had lower importance scores than less-experienced residents for 5 out of 25 attributes, and lower scores for six out of 25 attributes.

Satisfaction

- 2000-01 boating residents had significantly lower satisfaction scores than 1995-96 boating visitors for 24 out of 25 attributes.
- More-experienced residents had lower satisfaction scores than less-experienced residents for 3 out of 25 attributes.

Table 1. Comparisons of Importance-Satisfaction Scores: 1995-1996 and 2000-2001 Boating Samples

	Trend from 95-96 Sample, Boating Sample [2]							
	Visitors				Residents			
	Importance		Satisfaction		Importance		Satisfaction	
	Trend	Significance [1]	Trend	Significance [1]	Trend	Significance [1]	Trend	Significance [1]
I. Shoreline access	4.8%	**	-10.8%	**	-15.4%	**	-12.2%	**
H. Parks and specially protected areas	6.9%	**	-9.4%	**	-10.1%	**	-11.8%	**
J. Designated swimming/beach areas	8.8%	**	-9.6%	**	-13.4%	**	-14.6%	**
K. Mooring buoys near coral reefs	6.5%	**	-11.3%	**	-2.3%		-15.5%	**
D. Many different kinds of fish and sea life to catch	8.5%	**	-9.5%	**	7.5%	**	-11.3%	**
U. Cleanliness of streets and sidewalks	4.0%	**	-9.2%	**	-12.6%	**	-5.9%	**
B. Amount of living coral on reefs	8.3%	**	-10.4%	**	-2.6%	**	-14.2%	**
V. Uncrowded conditions	7.4%	**	-13.8%	**	0.8%		-13.9%	**
N. Historic preservation	7.3%	**	-8.7%	**	-13.0%	**	-13.4%	**
W. Maps, brochures, and other tourist info	7.1%	**	-8.9%	**	-16.8%	**	-14.3%	**
E. Opportunity to view large wildlife	10.1%	**	-12.5%	**	0.4%		-7.1%	**
L. Marina facilities	6.4%	*	-10.1%	**	-10.5%	**	-14.8%	**
F. Large Numbers of Fish	10.7%	**	-9.5%	**	-2.2%		-13.3%	**
O. Parking	7.3%	**	-11.8%	**	-30.3%	**	-8.5%	**
R. Condition of bike paths and sidewalks/paths	3.7%		-11.8%	**	-16.0%	**	-7.1%	**
G. Quality of beaches	5.7%	**	-11.5%	**	-5.4%	**	-16.6%	**
M. Boat ramps/launching facilities	1.6%		-13.3%	**	-15.8%	**	-13.3%	**
T. Availability of public restrooms	4.7%	**	-6.3%	**	-12.1%	**	-12.6%	**
S. Condition of roads and streets	2.4%		-10.0%	**	-19.4%	**	-6.1%	**
X. Service and friendliness of people	2.2%		-6.5%	**	-9.0%	**	-9.7%	**
Q. Directional signs, street signs, mile markers	3.4%		-10.7%	**	-23.3%	**	-12.7%	**
P. Public transportation	12.4%	**	-8.6%	**	-20.6%	**	0.1%	
Y. Value for the price	4.8%	**	-11.5%	**	-8.1%	**	-7.2%	**
C. Many different kinds of fish and sea life to view	9.6%	**	-10.0%	**	-1.8%		-10.2%	**
A. Clear Water (high visibility)	7.5%	**	-2.6%		-2.6%	**	-13.0%	**

1. Based on t-test. ** denotes significance at 5% level, * denotes significance at the 10% level.
2. Includes only those who participated in boating activities from the 95-96 sample.

Key Areas of Concern and Priority Areas of Concern

The importance-satisfaction analytical framework is used to identify key areas of concern, then to prioritize them. Figures 2 and 3 both present a series of three four-quadrant graphs. In both Figures 2 and 3, the first (left) graph plots attributes of the 1995-96 boating sample. The reason for the inclusion of these scores is, as mentioned above, the 2000-01 survey only included boaters. Therefore, this is the starting point to estimate the trend toward the 2000-01 samples. The middle graph plots the 2000-01 scores against the crosshairs of the 1995-96 boater sample mean scores. With this graph, the trend in scores is illustrated by showing the relative placement of 2000-01 scores to 1995-96 sample means. The left and middle graphs identify key areas of concern. The third (right) graph of each figure contains the 2000-01 scores plotted against the crosshairs of the 2000-01 sample. This is a static matrix and is used to gauge the relative perceptions of users in the 2000-01 sample and to identify priority areas of concern.

Table 2. Comparisons of Importance-Satisfaction Scores based on Experience: 2000-2001 Sample

	2000-2001 Sample Comparison Based on Experience [2]							
	Visitors				Residents			
	Importance		Satisfaction		Importance		Satisfaction	
	Comparis	Significance [1]	Comparis	Significance [1]	Comparis	Significance [1]	Comparis	Significance [1]
I. Shoreline access	0.9%		-11.0%	**	-12.8%	**	-5.6%	
H. Parks and specially protected areas	-1.8%		-12.7%	**	-7.0%		-5.3%	
J. Designated swimming/beach areas	-4.3%		-5.8%		-4.3%		-1.1%	
K. Mooring buoys near coral reefs	9.0%	*	-14.9%	**	-5.7%		-4.2%	
D. Many different kinds of fish and sea life to catch	24.3%	**	-12.1%	**	-3.5%		-4.9%	
U. Cleanliness of streets and sidewalks	-1.6%		-10.6%	**	-0.3%		6.6%	
B. Amount of living coral on reefs	4.4%		-10.8%	**	-0.2%		-2.4%	
V. Uncrowded conditions	-0.7%		-11.8%	**	0.3%		-10.3%	*
N. Historic preservation	-0.4%		-5.3%		-0.5%		-7.4%	
W. Maps, brochures, and other tourist info	-6.3%		-10.2%	**	1.0%		-9.1%	
E. Opportunity to view large wildlife	0.1%		-11.2%	**	-7.7%	**	7.7%	
L. Marina facilities	12.4%	*	1.6%		-3.6%		-8.2%	
F. Large Numbers of Fish	9.5%	**	-12.9%	**	-5.9%	*	-7.8%	
O. Parking	-3.8%		-11.3%	**	-16.4%	*	0.0%	
R. Condition of bike paths and sidewalks/paths	-2.3%		-10.8%	**	-2.9%		1.8%	
G. Quality of beaches	-4.7%		-6.3%		-1.7%		-6.3%	
M. Boat ramps/launching facilities	24.9%	**	4.1%		-3.0%		-11.8%	*
T. Availability of public restrooms	-6.3%	*	-9.3%	**	-7.8%		3.0%	
S. Condition of roads and streets	-1.3%		-13.7%	**	-6.5%		3.2%	
X. Service and friendliness of people	-4.8%	*	-10.4%	**	4.7%		-0.9%	
Q. Directional signs, street signs, mile markers	-2.9%		-5.5%		-16.6%	**	-6.0%	
P. Public transportation	-12.2%		-11.7%	*	-11.4%		-2.2%	
Y. Value for the price	0.6%		-9.2%	*	-4.4%		1.8%	
C. Many different kinds of fish and sea life to view	2.6%		-9.4%	**	-4.0%		-3.9%	
A. Clear Water (high visibility)	0.6%		-6.1%		-6.1%	**	-13.1%	**

1. Based on t-test. ** denotes significance at 5% level, * denotes significance at the 10% level.
2. Analysis is a comparison between those with less than five years to those with greater than, or equal to five years experience.
A "+" denotes a higher score with higher experience and a "-" denotes a lower score with higher experience.

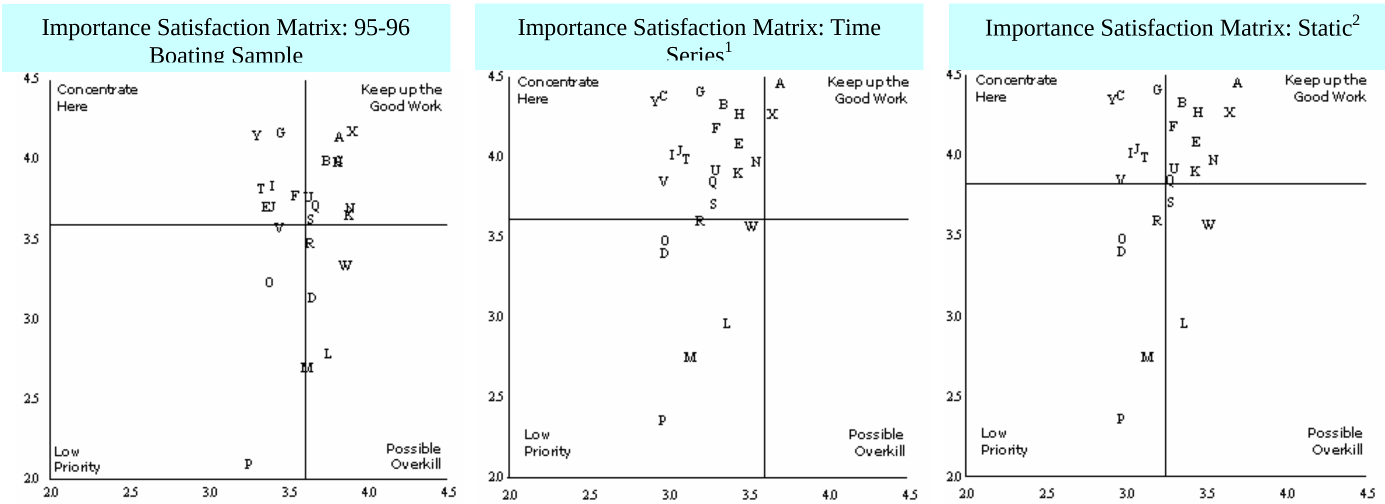


Figure 2. Importance-satisfaction matrices 1995-96 and 2000-01: visitor surveys.

1. This matrix shows the 2000-01 attributes plotted on the matrix; the mean score crosshairs are from the 1995-96 boating sample. The attributes of the 1995-96 boating sample are shown in the graph to the left. In this way the trend of each attribute is illustrated.
2. This matrix simply shows the 2000-01 attributes plotted with the 2000-01 mean score lines.

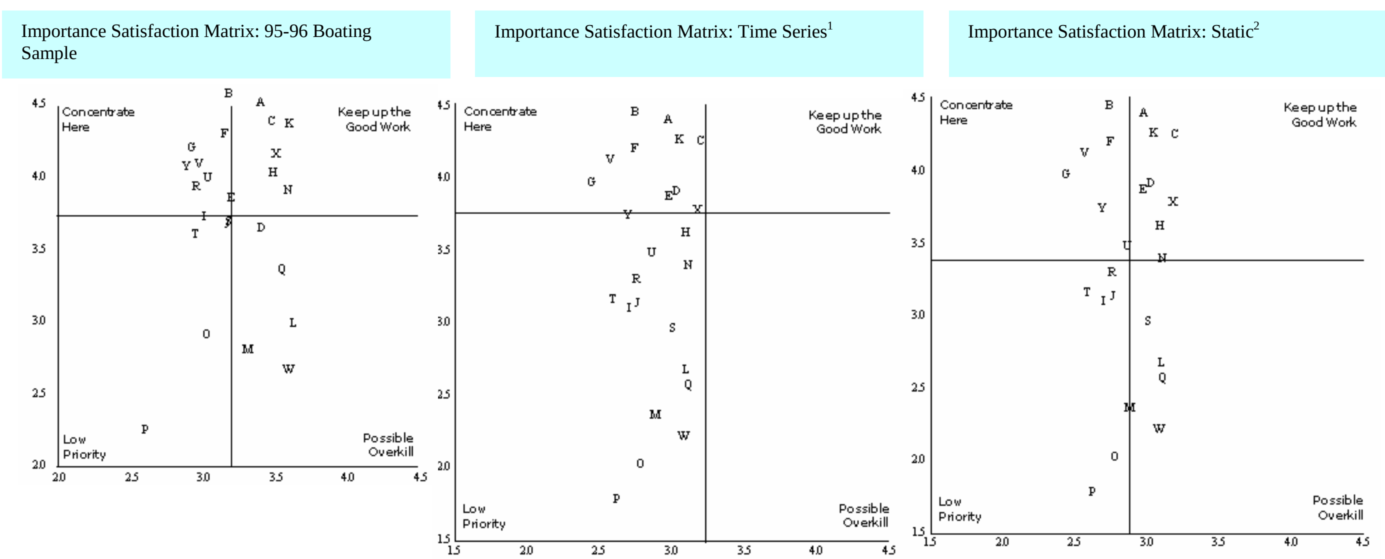


Figure 3. Importance-satisfaction matrices 1995-96 and 2000-01: resident surveys.

1. This matrix shows the 2000-2001 attributes plotted on the matrix; the mean score crosshairs are from the 1995-1996 boating sample. The plotted attributes of the 1995-1996 boating sample are shown in the graph to the left. In this way the trend of each attribute is illustrated.
2. This matrix simply shows the 2000-2001 attributes plotted with the 2000-2001 mean score lines.

Key Areas of Concern: Visitors

The results presented in the first two graphs in Figure 2 are summarized in Table 3. There has been a marked decline in satisfaction scores between the 1995-96 and 2000-01 survey periods. In the 1995-96 survey, there were seven attributes located in the “concentrate here” quadrant. In the 2000-01 survey, these same seven attributes remained in this quadrant and were joined by nine additional attributes. Additionally, five attributes moved from the “possible overkill” quadrant to the “low priority” quadrant, and two attributes were in the “low priority” quadrant in both survey periods. Finally, two attributes, A and X, were in the “keep up the good work” quadrant for both survey periods.

Table 3. Areas of concern: trends in attributes.

Visitor Survey

Concentrate Here		
1995-1996	2000-2001[1]	
E	**B**	***K***
F	**C**	**N**
G	**E**	**Q**
I	**F**	**S**
J	**G**	**T**
T	**H**	***U***
Y	**I**	**V**[2]
	J	**Y**

1. Attributes in red moved from "Keep up the Good Work" to "Concentrate Here" in 2000-2001
2. This attribute moved from “Low Priority” to “Concentrate Here”

Visitor Key Areas of Concern: 2000-01

Natural Resources
* Amount of living coral on the reefs
* Many different kinds of fish and sea life to view
  Opportunity to view large wildlife: manatees, whales, dolphins, and sea turtles
  Large numbers of fish
  Quality of beaches

Natural Resource Facilities
* Parks and specially protected areas
  Shoreline access
  Designated swimming/beach areas
* Mooring buoys near coral reefs

Other Facilities
* Historic preservation (historic landmarks, houses, etc.)
* Directional signs, street signs, mile markers
* Condition of roads and streets
  Availability of public restrooms
* Cleanliness of streets and sidewalks
* Uncrowded conditions

Services
  Value for the Price

* Was not a key area of concern in 1995-96.

Key Areas of Concern: Residents

The results presented in the first two graphs in Figure 3 are summarized in Table 4. There has been a significant decline in satisfaction scores between the 1995-96 and 2000-01 survey periods. In the 1995-96 survey, there were nine attributes located in the "concentrate here" quadrant. In the 2000-01 survey, there were ten attributes in the "concentrate here" quadrant, five of which were in this quadrant in the 1995-96 survey, four of which moved from the "keep up the good work" category, and one attribute from the "possible overkill" category. Additionally, four attributes moved from the "concentrate here" quadrant to the "low priority" quadrant, four attributes moved from the "possible overkill" quadrant to the "low priority" quadrant, and five attributes were in the "low priority" quadrant in both survey periods. It is important to note that there are no 2000-01 attributes to the right of 1995-96 vertical mean satisfaction line in the middle graph, meaning there was no improvement in relative satisfaction ratings for any item.

Table 4. Areas of concern: trends in attributes.
Resident Survey

Concentrate Here			
1995-1996		2000-2001[1]	
B	**R**	**A**	**F**
E	**U**	***B***	**G**
F	**V**	**C**	***K***
G	**Y**	**D**[2]	**V**
I		**E**	***X***
			Y

1. Attributes in red moved from "Keep up the Good Work" to "Concentrate Here" in 2000-2001
2. Moved from "Possible Overkill" to "Concentrate Here"

Resident Key Areas of Concern: 2000-01

Natural Resources
* Clear water (high visibility)
Amount of living coral on the reefs
* Many different kinds of fish and sea life to view
* Many different kinds of fish and sea life to catch
Opportunity to view large wildlife: manatees, whales, dolphins, and sea turtles
Large numbers of fish
Quality of beaches

Natural Resource Facilities
* Mooring buoys near coral reefs

Other Facilities
* Uncrowded conditions

Services
* Service and friendliness of people
Value for the Price

* Was not a key area of concern in 1995-96.

Priority Areas of Concern

In Figures 2 and 3, the first two graphs were calibrated using 1995-96 baseline means for importance and satisfaction scores to analyze trends. In the third graph in each figure, the graph is calibrated using 2000-01 mean scores for importance and satisfaction. This allows us to assess the relative importance-satisfaction in 2000-01 to help establish priority areas of concern.

Priority Areas of Concern: Visitors
Ten attributes fell in the "keep up the good work" category, three attributes fell in the "possible overkill" category, and five attributes fell into the "low priority" category. Additionally, seven attributes fell into the "concentrate here" category. They are: C) Many different kinds of fish and sea life to view, G) Quality of beaches, I) Shoreline access, J) Designated swimming/beach areas, T) Availability of public restrooms, V) Un-crowded conditions, and Y) Value for the price.

Priority Areas of Concern for Visitors: 2000-01

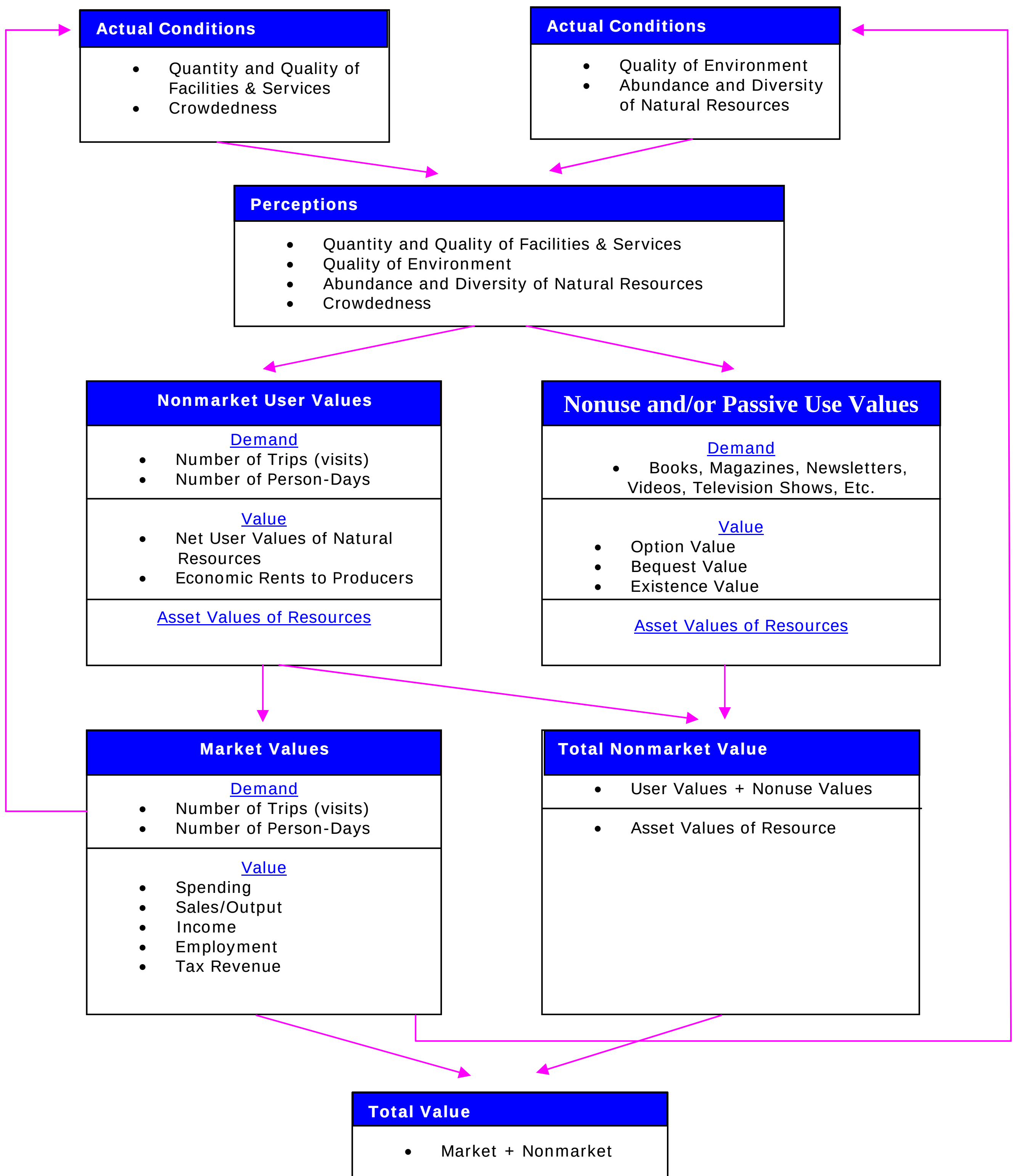
Natural Resources
Many different kinds of fish and sea life to view
Quality of the beaches
Natural Resource Facilities
Shoreline access
Designated swimming/beach areas
Other Facilities
Availability of public restrooms
Uncrowded conditions
Services
Value for the Price

Priority Areas of Concern: Residents
Eight attributes fell in the "keep up the good work" category, four attributes fell in the "possible overkill" category, and seven attributes fell into the "low priority" category. Additionally, six attributes fell into the "concentrate here" category - these include: B) Amount of living coral on reefs, F) Large numbers of fish, G) Quality of beaches, U) Cleanliness of streets and sidewalks, V) Un-crowded conditions, and Y) Value for the price.

Priority Areas of Concern for Residents: 2000-01

Natural Resources
Amount of living coral on the reefs
Large numbers of fish
Quality of the beaches
Other Facilities
Cleanliness of streets and sidewalks
Uncrowded conditions
Services
Value for the Price

Interpretations and Conclusions
Interpretation of the results in this study requires a conceptual model. Such a model was provided in Leeworthy and Bowker (1997) and is reproduced here (see Fig. 4).



Source: Leeworthy and Bowker 1997

Figure 4. Conceptual model linking the economy and the environment.

The "Conceptual Model Linking the Economy and Environment" shows how both market and nonmarket economic values are linked to both "actual conditions" of the natural environment and the quantity and quality of facilities and services as well as people's "perceptions" of these conditions.

Although there is a direct connection between actual and perceptions of conditions and market and nonmarket economic values, there may be lags (delays in time) between perceptions of conditions and changes in their behavior and/or preferences, which lead to changes in demand and market and nonmarket economic values. Also, there may be differences in changes in actual conditions (as measured by ecological monitoring) and perceived conditions (as measured by socioeconomic monitoring).

Time delays in people's responses (lags) to changed conditions (actual or perceived) present opportunities. If actual or perceived conditions are in decline, there may be time to either correct actual conditions (i.e., make the necessary investments to improve conditions) or if there is a difference in actual and perceived conditions (ecological and socioeconomic monitoring results are not in agreement), then opportunities exist to apply education and outreach efforts to correct misperceptions. In both cases, the objective is to avoid negative economic outcomes.

Our results show that many key natural resource attributes, facilities, and services have increased in importance to people, while satisfaction with these natural resource attributes, facilities, and services has declined. Plugging these results into our conceptual model linking the economy and environment leads to potentially dire predictions of the future natural resource-based economy if actions are not taken to reverse these trends.

Another possible consequence of negative trends in satisfaction is the cost of attracting and educating "new" visitors. Our results show that for many natural resource attributes, facilities, and services, satisfaction ratings are not only in decline, they are also relatively lower for more-experienced visitors. The loss of repeat visitors raises the marketing costs of attracting "new" visitors and raises the costs of educating "new" visitors on how to interact with the areas' natural resources and support sustainable tourism. Borrowing a phrase from the clothing retailer Syms, "An educated consumer is our best customer."

References

Guadagnolo, F. 1985. The importance-performance analysis: an evaluation and marketing tool. Journal of Park and Recreation Administration 3 (2): 13-22.

Hollenhorst, S., D. Olson, and R. Fortney. 1992. Use of importance-performance analysis to evaluate State Park cabins: the case of the West Virginia Park System. Journal of Park and Recreation Administration 10 (1): 1-11.

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2003a. Socioeconomic study of reefs in southeast Florida. Final Report October 19, 2001 as revised April 18, 2003 from Hazen and Sawyer to Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Conservation Commission, and National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/Reefs/02-01.pdf

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2003b. Socioeconomic study of reefs in southeast Florida. Technical Appendix to Final Report October 19, 2001 as revised April 18, 2003 from Hazen and Sawyer to Broward County, Palm Beach County, Miami-Dade

County, Monroe County, Florida Fish and Wildlife Conservation Commission, and National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/Reefs/PDF's/Tech/TechApp.pdf

Leeworthy, V.R., and J.M. Bowker. 1997. Nonmarket economic user values of the Florida Keys/Key West. Silver Spring, MD: National Oceanic and Atmospheric Administration and Athens, GA: U.S. Forest Service. http://marineeconomics.noaa.gov/SocmonFK/publications/97-30.pdf

Leeworthy, V.R., and P.C. Wiley. 1996. Importance and satisfaction ratings by recreating visitors to the Florida Keys/Key West. Silver Spring, MD: National Oceanic and Atmospheric Administration. 23 pp. http://marineeconomics.noaa.gov/SocmonFK/publications/96-27.pdf

Leeworthy, V.R., and P.C. Wiley. 1997. A socioeconomic analysis of the recreation activities of Monroe County residents in the Florida Keys/Key West. Silver Spring, Maryland: National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/SocmonFK/publications/97-18.pdf

Leeworthy, V.R., P.C. Wiley, and J. Hospital. 2004. Importance-satisfaction ratings five-year comparison, SPA & ER use, and socioeconomic and ecological monitoring comparison of results 1995-96 to 2000-01. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Ocean Service, Office of Management and Budget, Special Projects Division.

Martilla, J.A., and J.C. James. 1977. Importance-performance analysis. Journal of Marketing 41 (1): 77-79.

National Oceanic and Atmospheric Administration (NOAA) – Florida Keys National Marine Sanctuary, U.S. Environmental Protection Agency, and State of Florida. 2003. Sanctuary Science Report 2001: An Ecosystem Report Card. Final: 21 March 2003. http://www.fknms.nos.noaa.gov/research_monitoring/welcome.html.

Richardson, S.L. 1987. An importance-performance approach to evaluating communication effectiveness. Journal of Park and Recreation Administration 5 (4): 71-83.

Linking Ecological and Socioeconomic Monitoring Results, 1995-96 to 2000-01

Vernon R. (Bob) Leeworthy, Peter C. Wiley and Justin Hospital (NOAA, National Ocean Service, Office of Management and Budget, Special Projects Division, Silver Spring, MD)

Goals

Our goals were to monitor and assess perceptions of recreational/tourist users as they relate to the market and nonmarket economic values of Sanctuary resources. Here, specifically, we test whether user perceptions of resource conditions are in agreement with what marine scientists are observing in actual conditions.

Methods

We chose to focus on four main attributes measured by FKNMS monitoring projects, with which we could integrate socioeconomic data from the 1995-96 study (Leeworthy and Wiley 1996) and the 2000-01 reef study (Johns et al. 2003a, b). These attributes were: 1) diversity of fish and other sea life, 2) abundance of fish, 3) amount of living coral on the reef, and 4) water clarity. We compared ecological monitoring results and socioeconomic results to investigate how these measurements contrasted with human perceptions of the performance of Sanctuary Preservation Areas (SPAs) and Ecological Reserves (ERs) within the FKNMS.

Comparisons were made between socioeconomic and ecological monitoring from two perspectives. First, trends across the entire FKNMS were evaluated. For the socioeconomic measures we looked at the differences in mean satisfaction scores between 1995-96 and 2000-01. This was done for all boating visitors and residents and for more-experienced versus less-experienced visitor and resident boaters (more-experienced users were those with five or more years of boating experience). The socioeconomic and ecological measures are described in the full report (Leeworthy et al. 2004) and the ecological measures can be found in greater detail in NOAA et al. (2003). Second, SPAs and ERs were compared to reference areas. For socioeconomic measures, mean satisfaction ratings of SPA and ER users were compared with non-SPA and non-ER users.

Two-sample t-tests were used to test for differences in mean satisfaction scores using the 0.05 level of significance as a cut-off for determining significance (95% confidence level).

Key Findings

Overall FKNMS 1995-96 to 2000-01

<u>Water Clarity</u>

Socioeconomic and ecological monitoring was in agreement for visitors, i.e., there has been no change in water clarity. However, residents perceived that water clarity has declined, and this was more prevalent among more-experienced residents. This may indicate a need for education and outreach, if residents are misperceiving actual water clarity conditions.

<u>Diversity</u>

There was disagreement between socioeconomic and ecological monitoring results regarding diversity of marine life. Users perceived a decline, while research results indicated that actual conditions are improving. There would appear to be a need for education and outreach to correct these misperceptions. Perhaps ratings on diversity were influenced by the status of the amount of living coral on reefs (see below).

Abundance

For this parameter users perceived significant declines, while ecological monitoring produced mixed results. There may be needs to both make greater investments in protecting and restoring resources and in education and outreach efforts.

Amount of Living Coral on Reefs

For living coral, socioeconomic and ecological monitoring was in agreement. Marine scientists observed significant declines in stony coral cover and increases in diseases, and users perceived the decline. There is a clear need to identify the sources and solutions to the problems. Given the higher use and economic value of natural versus artificial reefs in the FKNMS (see Johns et al. 2003), there is economic justification to make investments to solve these problems before they translate into economic losses.

Table 1: Reef User Perceptions vs. Ecological Observations: Overall FKNMS

	Socioeconomics (Satisfaction Scores)		
	Trends (95-96 vs. 00-01) [1]	Experienced vs. Less Experienced [2]	**Ecological**
Diversity			
Visitors	Significant Decline	Significantly Lower	Increase
Residents	Significant Decline	Lower – Not Significant	
Abundance			
Visitors	Significant Decline	Significantly Lower	Targeted species (+)
Residents	Significant Decline	Lower – Not Significant	Non-targeted species (+/-)
			Spiny Lobsters (-)
Amount of Living Coral			
Visitors	Significant Decline	Significantly Lower	37% Decline in stony coral cover
Residents	Significant Decline	Lower – Not Significant	Increase in disease infections
Water Clarity			
Visitors	Lower – Not Significant	Lower – Not Significant	No trend
Residents	Significantly Lower	Significantly Lower	

1. Trends are based on comparison of mean scores for 1995-96 samples of visitors and residents versus 2000-01 samples of visitors and residents. T-test for differences in means with significance cut-off at 0.05 or 95 percent confidence level
2. Experienced users are those with five or more years of experience in FKNMS. Statistical test is a T-test on mean satisfaction scores of experienced vs. less experienced samples of users from the 2000-01 survey. Significance cut-off is at 0.05 or 95 percent confidence level.

SPAs and ERs vs. Open (Reference) Areas

Water Clarity

Users did not perceive any changes in water clarity between SPAs and ERs and associated reference areas. This was consistent with ecological monitoring, which indicated that there would be no expected differences based on actual measurements.

Diversity

Overall, there was general agreement between socioeconomic and ecological monitoring. SPAs and ERs have increased in diversity relative to reference areas and visitors perceived the difference, while residents did not perceive the change.

Abundance

Both socioeconomic and ecological monitoring had mixed results regarding abundance. Overall, however, both socioeconomic and ecological monitoring supported the notion that SPAs and ERs provided benefits from improved quality of fully protected sites.

Amount of Living Coral on Reefs

There was only a small difference between the results of socioeconomic monitoring and ecological monitoring when comparing amount of living coral on reefs in SPAs and ERs versus reference areas. Visitors that used SPAs and ERs had slightly higher mean satisfaction scores than non-users, whereas there was no difference between resident reef users and non-users.

Table 2. Reef User Perceptions vs. Ecological Observations: Comparison of SPAs & ERs to Open (Reference) Areas

	Socioeconomics (Satisfaction Scores) 2000-01 Comparison: SPA & ER Users vs. Non-SPA & ER Users [1]	**Ecological**
Diversity		
Visitors	Significantly Higher	Higher for SPAs and ERs
Residents	Lower – Not Significant	
Abundance		
Visitors	Significantly Higher	Mixed Results
Residents	Lower – Not Significant	(see write-up)
Amount of Living Coral		
Visitors	Significantly Higher	No difference
Residents	Lower – Not Significant	
Water Clarity		
Visitors	Higher – Not Significant	No difference
Residents	No Difference	

1. Comparison of mean scores using T-test. Significance cut-off level is 0.05 or the 95 percent confidence level.

For the two items for which managers had expectations for improvement (e.g., diversity and abundance), SPAs and ERs appeared to be generating expected benefits. Visitors seemed more apt to perceive these benefits than residents.

References

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2003a. Socioeconomic study of reefs in southeast Florida. Final Report October 19, 2001 as revised April 18, 2003 from Hazen and Sawyer to Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Conservation Commission, and National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/Reefs/02-01.pdf

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2003b. Socioeconomic study of reefs in southeast Florida. Technical Appendix to Final Report October 19, 2001 as revised April 18, 2003 from Hazen and Sawyer to Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Conservation Commission, and National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/Reefs/PDF's/Tech/TechApp.pdf

Leeworthy, V.R., P.C. Wiley, and J. Hospital. 2004. Importance-satisfaction ratings five-year comparison, SPA & ER use, and socioeconomic and ecological monitoring comparison of results 1995-96 to 2000-01. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Ocean Service, Office of Management and Budget, Special Projects Division.

National Oceanic and Atmospheric Administration (NOAA) – Florida Keys National Marine Sanctuary, U.S. Environmental Protection Agency, and State of Florida. 2003. Sanctuary Science Report 2001: An Ecosystem Report Card. Final: 21 March 2003. http://www.fknms.nos.noaa.gov/research_monitoring/welcome.html.

Sanctuary Preservation Areas and Ecological Reserves: Monroe County Reef-Using Residents' Opinions on "No-Take" Zones

Vernon R. (Bob) Leeworthy, Peter C. Wiley and Justin Hospital (NOAA, National Ocean Service, Office of Management and Budget, Special Projects, Division, Silver Spring, MD)

Goals

Our goals were to monitor and assess knowledge, attitudes, and perceptions of Sanctuary management strategies and regulations. Here, specifically, we assess knowledge and attitudes toward fully protected ("no-take") marine zones by residents of Monroe County who use reefs in the Sanctuary.

Methods

The information presented here was obtained as part of a multi-agency partnership project entitled "Socioeconomic Study of Reefs in Southeast Florida, 2000-2001." Several modules of questions were added to a survey of both residents and visitors of Monroe County-FKNMS to contribute to objectives of the Recreation and Tourist component of the Socioeconomic Research and Monitoring Program for the FKNMS. One set of questions addressing opinions on no-take zones was designed for reef-using residents of Monroe County. Visitors were not asked these questions because the research team did not think they could control for the "not in my backyard (NIMBY) effect" within the time constraints of the survey. Also, the 2000-01 reef study was conducted from June 2000 through May 2001. The Tortugas Ecological Reserve did not go into effect until July 2001. Therefore, the Tortugas Ecological Reserve was not part of the 2000-01 survey results.

The sample of reef-using residents of Monroe County was identified by use of a stratified-random sample of registered boaters from the State of Florida's boat registration file. A mail survey was used with sampling stratified by boat size classifications (see Johns et al. 2003a, b). A total of 790 questionnaires were returned; 594 (75%) used their boats on reefs in Monroe County-FKNMS.

The 2000-01 Reef Study gathered opinions of Monroe County reef-using residents toward no-take zones. The survey provided an introductory statement explaining the nature of no-take zones, the distinction between Sanctuary Preservation Areas (SPAs) and Ecological Reserves (ERs), how many of each currently exists, and areas encompassed by SPAs and ERs. After this background information, the survey then questioned residents' opinions concerning their support for the current no-take zones and possible expansion of them.

A nonparametric statistical test, the Kolmogorov-Smirnov Two-Sample test, was used for testing for differences in responses to the yes/no questions and a two-sample t-test was used for differences in the mean percentage of coral reef to be protected. A 0.05 level of significance was used as the cut-off value for statistical significance (95% confidence level).

Findings to Date

The first question asked Monroe County reef-using residents whether they supported the currently designated no-take zones in the Florida Keys. For all resident reef users, an overwhelming majority supported the existing no-take zones (78% - see Table 1). Also, there was no significant difference between all reef users and recreational fishermen (76% supported the no-take zones). While the majority of respondents favored the current design of no-take zones in the FKNMS, a higher proportion of resident SPA and ER users favored the currently designated no-take zones than non-SPA- and non-ER-using residents (Table 2). These differences were statistically significant.

Not in My Backyard Hypothesis
Questions two and three tested the "NIMBY" (Not In My Backyard) hypothesis by asking residents whether they supported the creation of new no-take zones in the waters off the three counties to the north (Palm Beach, Broward, and Miami-Dade) versus whether they supported additional no-take zones in Monroe County.

The results do not support the NIMBY hypothesis. The results were, in fact, opposite of what was expected. Monroe County reef-using residents were generally not in support of no-take zones in the three counties to the north, while supporting the creation of additional no-take zones in Monroe County-FKNMS. SPA- and ER-users supported both additional no-take zones in the three counties to the north and additional no-take zones in Monroe County-FKNMS, while non-users were much less supportive (less than a majority for both options).

Table 1. Opinions on "no-take" zones: all residents vs. recreational fishermen.

Question	All Reef Users (% Yes)	Recreational Fishermen (% Yes)
1. Do you support currently designated "No Take" zones in the Florida Keys?	78%	76%
2. Would you support creation of additional "No Take" zones on some of the reefs in Palm Beach, Broward, and Miami-Dade Counties?	44%	39%
3. Would you support the creation of additional "No Take" zones on some of the reefs in your county of residence?	57%	55%
4. What percentage of the coral or natural reefs in southeast Florida do you think would be a reasonable proportion to protect by giving them "No Take" designation?	Mean: 32% Median: 25% Mode: 0%	27% 20% 0%

Source: Leeworthy et al. (2004)

Proportion of Reefs that Should be Protected
Question four asked what percentage of coral or natural reefs in southeast Florida residents felt would be a reasonable proportion to protect by giving them no-take designation.

The all reef-using-resident mean was about 32%, and 27% for reef-using recreational fishers. This implies that, of the survey respondents, Monroe County residents desired, on average, that 32% of coral or natural reefs in southeast Florida be protected through no-take designations. Looking at the disaggregated breakdown of SPA and ER users versus non-users, the support for no-take designation varied significantly. On average, SPA- and ER-users supported a no-take percentage of 35%, while non-users, on average, supported designation at the level of 26%.

Using a more conservative measure of central tendency (the median) indicated that 50% of SPA- and ER-using residents would support that 25% or more of coral reefs be protected in no-take zones, while 50% of non-using residents would support that 20% or more of coral reefs be protected in no-take zones (Table 2).

Comparison of the mean and median showed that SPA- and ER-users desired higher levels of protection than non-SPA- and non-ER-users (differences in means and medians were statistically significant). Comparison of the modes (the mode indicates the most common response) showed that, for SPA- and ER-users, the desired protection level was 50%, while the mode for non-SPA- and non-ER-users was 0%. These results indicate that there was a large rift between resident SPA- and ER-users and non-SPA- and non-ER-using residents in willingness to protect corals or natural reefs in southeast Florida through no-take designations.

Table 2. Opinions on "no-take" zones: SPA and ER users vs. non-users.

Question	SPA & ER Users (% Yes)	Non Users (% Yes)
1. Do you support currently designated "No Take" zones in the Florida Keys?	83%	72%
2. Would you support creation of additional "No Take" zones on some of the reefs in Palm Beach, Broward, and Miami-Dade Counties?	51%	35%
3. Would you support the creation of additional "No Take" zones on some of the reefs in your county of residence?	63%	49%
4. What percentage of the coral or natural reefs in southeast Florida do you think would be a reasonable proportion to protect by giving them "No Take" designation?	Mean: 35% Median: 25% Mode: 5 0%	26% 20% 0%

Source: Leeworthy et al. (2004)

References

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2003a. Socioeconomic study of reefs in southeast Florida. Final Report October 19, 2001 as revised April 18, 2003 from Hazen and Sawyer to Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Conservation Commission, and National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/Reefs/02-01.pdf

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2003b. Socioeconomic study of reefs in southeast Florida. Technical Appendix to Final Report October 19, 2001 as revised April 18, 2003 from Hazen and Sawyer to Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Conservation Commission, and National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/Reefs/PDF's/Tech/TechApp.pdf

Leeworthy, V.R., P.C. Wiley, and J. Hospital. 2004. Importance-satisfaction ratings five-year comparison, SPA & ER use, and socioeconomic and ecological monitoring comparison of results 1995-96 to 2000-01. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Ocean Service, Office of Management and Budget, Special Projects Division.

SPAs and ERs: Baseline Estimates of Use, Importance-Satisfaction Ratings, Economic User Value, and Comparative Socioeconomic Profiles of Users and Non-Users, 2000-01

Vernon R. (Bob) Leeworthy, Peter C. Wiley, and Justin Hospital (NOAA, National Ocean Service, Office of Management and Budget, Special Projects Division, Silver Spring, MD)

Goals

The primary goal of socioeconomic monitoring is to detect and document resultant changes in Sanctuary resource utilization patterns and their impact on market and nonmarket economic values of Sanctuary resources. Toward that goal, a major objective is to monitor the spatial pattern and intensity of on-water recreational use, especially with regard to activities inside Sanctuary Preservation Areas (SPAs) and Ecological Reserves (ERs). Another major objective is to monitor and assess visitor and resident knowledge of Sanctuary management strategies and regulations, and their attitudes and perceptions regarding their appropriateness and effectiveness. Here we establish baselines of SPA and ER use, economic user value, and user perceptions of conditions of SPAs and ERs.

Methods

Baseline measurements for the Recreation and Tourism component of the Socioeconomic Research and Monitoring Program for the FKNMS were obtained in a 1995-96 study entitled "Linking the Economy and Environment of the Florida Keys/ Florida Bay." However, in our baseline year of 1995-96, SPAs and ERs, also referred to as "no-take" zones, were not yet in existence. Funding was not available to replicate this study once the boundaries of the SPAs and ERs were known to establish baselines before SPA and ER regulations went into effect. The information presented here was obtained from a multi-agency partnership project entitled "Socioeconomic Study of Reefs in Southeast Florida, 2000-2001" (see Johns et al. 2003a, b). We were able to add several modules of questions to the 2000-01 surveys about use of SPAs and ERs. From the broader survey, we were also able to produce comparative socioeconomic profiles of SPA- and ER-users versus non-users, comparative importance and satisfaction scores, and estimates of economic user value. Nineteen SPAs and ERs, which were open to nonconsumptive recreation activities, and four Special Use Areas, which were closed to recreational activities, went into effect on July 1, 1997. The Tortugas Ecological Reserve went into effect on July 1, 2001. The "Socioeconomic Study of Reefs in Southeast Florida" was for the period June 2000 through May 2001. Therefore, the Tortugas Ecological Reserve was not part of the 2000-01 survey results.

Findings

SPA and ER Use

In 2000-01, 57.8% of resident reef users used SPAs and/or ERs versus 44.3% of all visitor reef users. For visitors, a fairly high proportion (16.5%) didn't know whether they used a SPA or ER.

In the 2000-01 reef study, three types of use were measured in SPAs and ERs: 1) snorkeling, 2) scuba diving, and 3) glass-bottom boat rides. Glass-bottom boat rides were limited to visitors. All three activities were measured in terms of person-days of use, where a person-day included a whole day or any part of a day. Numbers of dives were also measured for snorkeling and scuba diving. Here, person-days are reported to relate SPA and ER use to total reef use for both residents and visitors.

In 2000-01, over 1.24-million person-days were spent in SPAs and ERs. This represented 45% of all reef use (natural and artificial) in the FKNMS, and 63% of all natural reef use in the FKNMS.

Visitors accounted for over 649,000 person-days of activity in SPAs and ERs (52% of all person-days in the SPAs and ERs), while residents accounted for over 593,000 person-days of activity in SPAs and ERs (Table 1).

There were almost 1.2-million person-days of snorkeling and scuba diving in SPAs and ERs and 58,540 glass-bottom boat rides. Resident and visitor snorkeling and scuba diving person-days were almost equal, with residents spending an estimated 593,000 person-days versus 590,000 person-days for visitors (Table 1).

Table 1. Sanctuary Preservation Area and Ecological Reserve use (person-days) in the FKNMS: 2000-2001.

	Person-Days			
	Snorkeling and Scuba Diving	Glass-bottom Boat Rides	Total	% of Total
Residents	593,400	N/A	593,400	47.75
Visitors	590,700	58,500	649,200	52.25
Total	1,184,100	58,500	1,242,600	100.00

Although 57.8% of residents used a SPA or ER, they only spent 36.3% of their total snorkeling and scuba diving person-days in the FKNMS inside SPAs and ERs. By contrast, 44.3% of visitors used a SPA or ER, but 50.9% of their snorkeling and scuba diving took place in SPAs and ERs, and 72.7% of visitor glass-bottom boat rides were in SPAs and ERs.

If we restrict our view to natural reef use, residents spent 56.2% of their snorkeling and scuba diving person-days on natural reefs inside SPAs and ERs. Visitors spent 64% of all their snorkeling and scuba diving person-days on natural reefs inside SPAs and ERs. Visitors also spent 82% of their glass-bottom boat rides on natural reefs inside the SPAs and ERs.

Comparative Socioeconomic Profiles

Users versus Non-Users of SPAs and ERs

In the 2000-01 reef study, we obtained socioeconomic profiles of users including such variables as age, sex, race/ethnicity, education level, household income, membership in fishing or diving clubs, years of experience boating in south Florida, use of artificial or natural reefs, and party size. These variables were obtained for both resident and visitor samples. For residents (all were boating residents that used artificial or natural reefs), we also obtained boat size. For visitors, we identified whether they owned their boat; many visitors use charter/party boats or guide services.

When comparing SPA- and ER-users to non-SPA- and non-ER-users, statistical tests were used. For discrete variables or categorical variables, a nonparametric test for differences in distribution (Kolmogorov-Smirnoff two-sample test) was used. For continuous variables, like age or experience, a t-test for differences in means, and a Kolmogorov-Smirnov two-sample test for differences in empirical distribution (whether the bar charts are showing significant differences) were used. A 0.05 level of significance was used as the cut-off point (i.e., 95% confidence level).

Generally, there were few differences between SPA- and ER-users and non-SPA- and non-ER-users. Significant differences were found for age, party size, and type of reef use. See Leeworthy et al. (2004) for full profile results.

Age

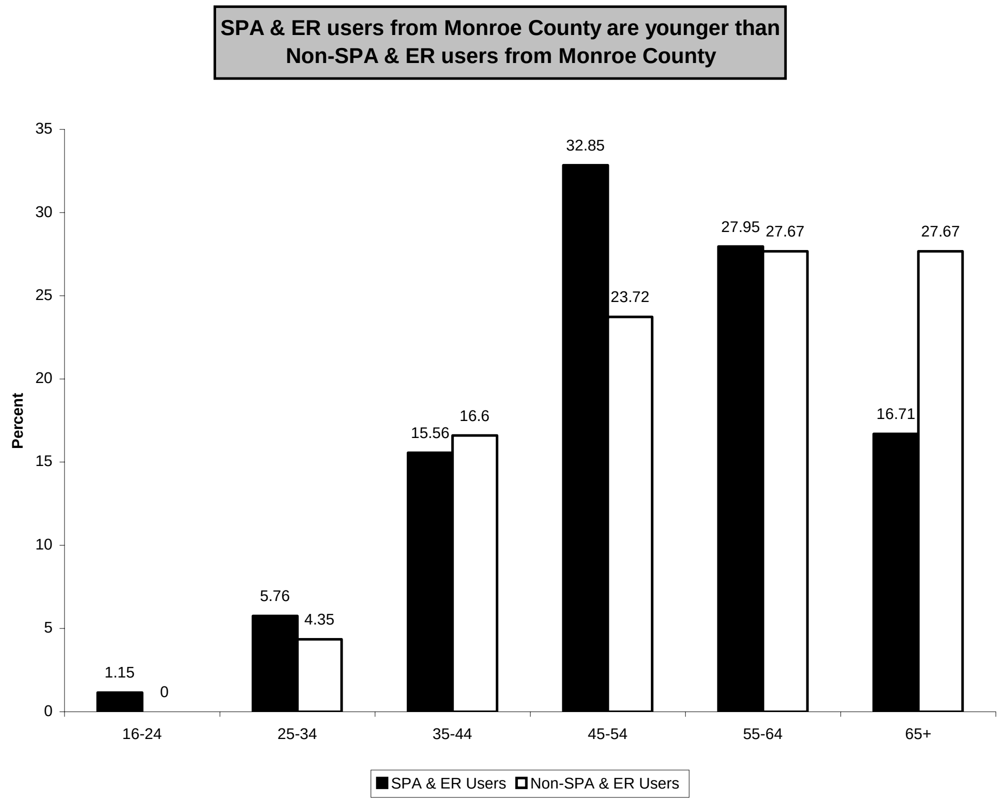
For both residents and visitors, SPA- and ER-users were, on average, younger than non-SPA- and non-ER-users (Fig. 1 and 2).

Party Size

Visitor SPA- and ER-users had slightly larger party sizes than non-SPA- and non-ER-using visitors. For residents there were no differences in party size between SPA- and ER-users and non-SPA- and non-ER-users (Fig. 3).

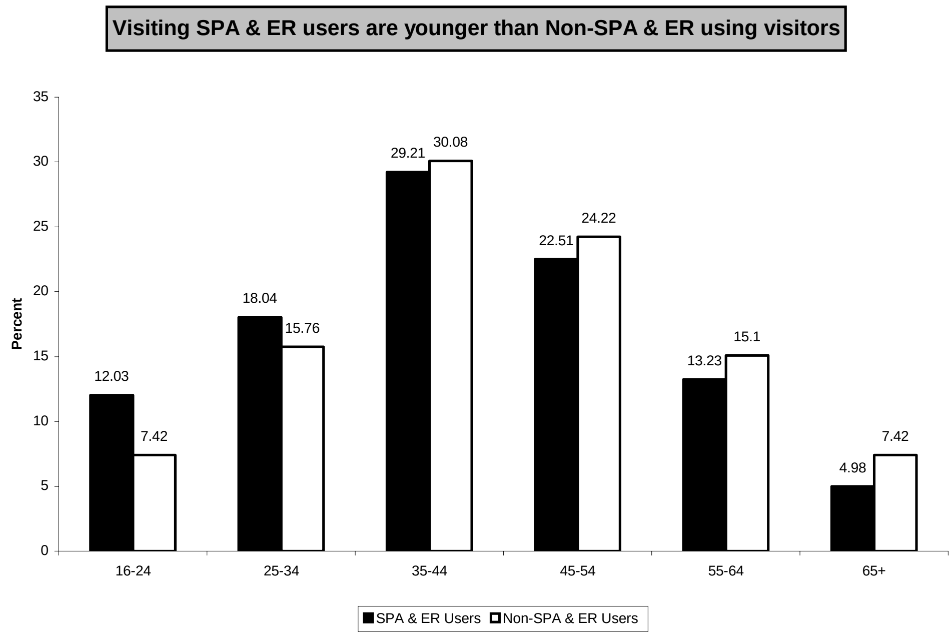
Type of Reef Use

Resident SPA- and ER-users had a higher likelihood of using artificial reefs than non-SPA- and non-ER-using residents. For visitors, SPA- and ER-users had a higher likelihood of using natural reefs than non-SPA- and non-ER-using visitors (Fig. 4 and 5).



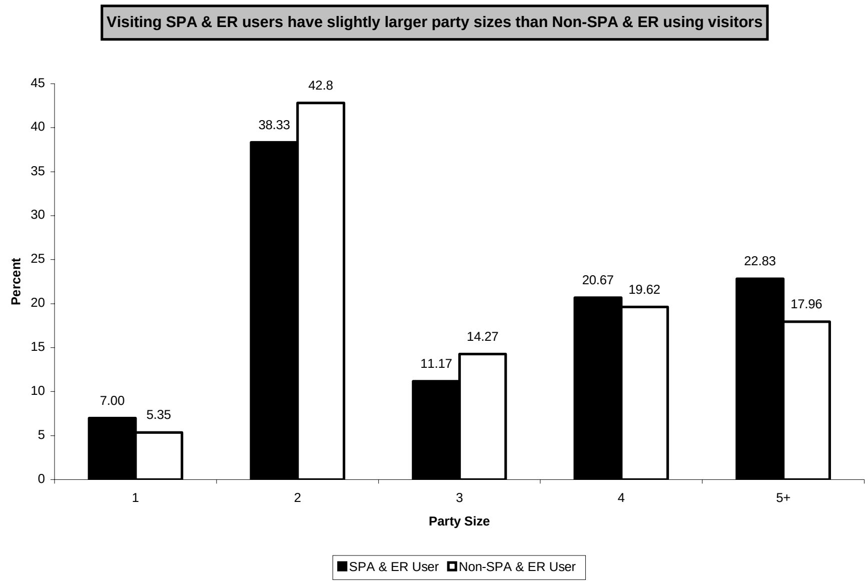
	SPA- & ER-users	Non-SPA- & non-ER-users
Minimum	17	12
Maximum	81	85
Mean	52.67	55.67
Median	53.00	57
Mode	46	57

Figure 1. Age: comparison of resident SPA- and ER-users with non-users.



	SPA- & ER-users	Non-SPA- & non-ER-users
Minimum	16	16
Maximum	77	83
Mean	41.50	44.48
Median	41.00	43.50
Mode	42.00	40.00

Figure 2. Age: comparison of visiting SPA- and ER-users with non-users.



	SPA- & ER-users	Non-SPA- & non-ER-users
Minimum	1	1
Maximum	48	40
Mean	4.26	3.51
Median	3.00	3.00
Mode	2.00	2.00

Figure 3. Party size: comparison of visiting SPA- and ER-users with non-users.

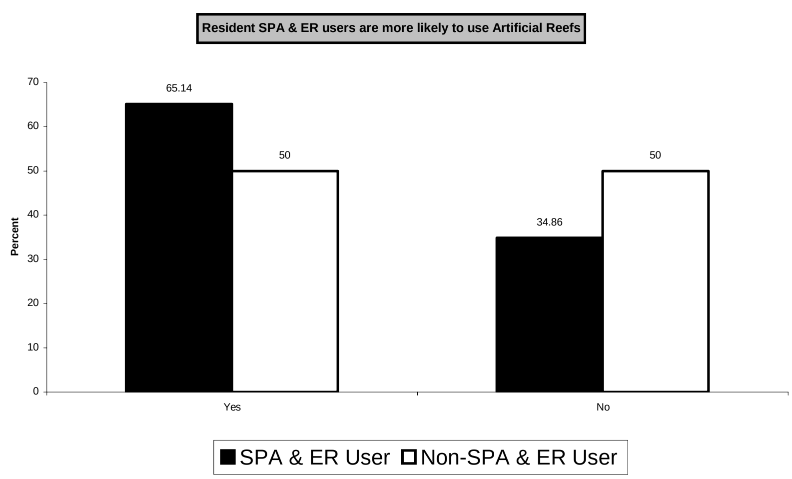


Figure 4. Artificial reef use: comparison of resident SPA- and ER-users with non-users.

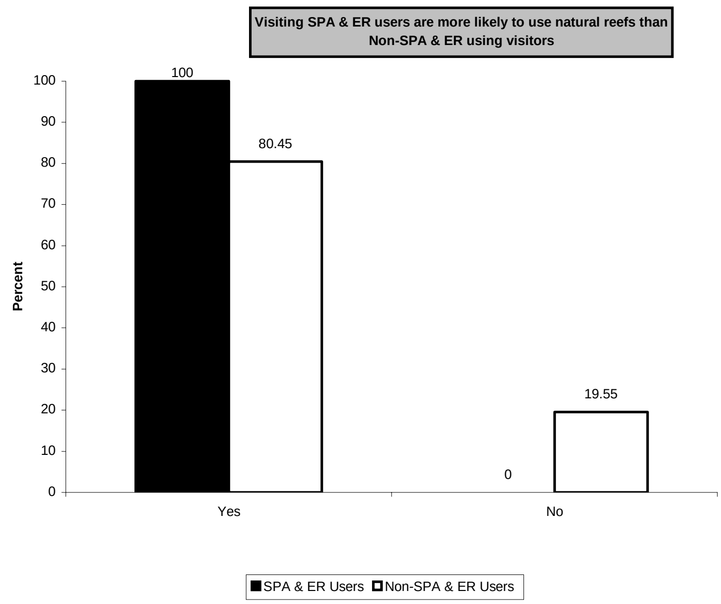


Figure 5. Natural reef use: comparison of visiting SPA- and ER-users with non-users.

Economic User Value

Economic user values (consumer's surplus – value over and above what users pay for reef use) were estimated for each visitor and resident in the 2000-01 samples (see Johns et al. 2003a, b) and compared between SPA- and ER-users and non-users.

Visitors

Visitor SPA- and ER-users had significantly higher economic user values for artificial reefs, natural reefs, and all reefs combined than non-SPA- and non-ER-using visitors, when measured on a per-party, per-trip basis. However, because visitor SPA- and ER-users had significantly larger party sizes than non-SPA- and non-ER-users, there was no difference in economic user values when normalized on a per-person-trip or per-person-day basis.

Using a weighted average of user value per person-day for snorkeling and scuba diving from Johns et al. (2003) for natural reef use and multiplying by the number of person-days of diving by visitors in SPAs and ERs yielded an estimated total annual user value of diving in SPAs and ERs of about $11.5 million. Following the same procedure for glass-bottom boat rides yielded an annual user value of $1.3 million; visitors had a total annual user value of SPAs and ERs of about $12.8 million (Table 2).

Residents

There were no statistically significant differences between resident SPA- and ER-users and non-SPA- and non-ER-using residents.

Using a weighted average of user value per person-day for snorkeling and scuba diving from Johns et al. (2003) for natural reef use and multiplying by the number of person-days of diving by residents in SPAs and ERs yielded an estimated total annual user value of diving in SPAs and ERs of about $5.5 million (Table 2).

Visitors and Residents

For all diving use by both visitors and residents, SPAs and ERs generated almost $17 million annually in economic user value and another $1.3 million for glass-bottom boat rides; SPAs and ERs had a total annual user value of $18.3 million (Table 2). Capitalizing this $18.3 million in annual user value using a discount rate of 3% and assuming this annual flow of value continues in perpetuity, we can derive an estimate of the asset value of SPAs and ERs. Asset value represents what someone would be willing to pay today for the right to own SPAs and ERs if they could charge a price for their use. The asset value was estimated to be $610 million ($18.3 million divided by 0.03).

Both annual user value and the asset value are likely under-estimates of economic user value because SPAs and ERs are probably not used to full capacity and future use is likely to increase. Also, it is likely that user value per unit of use (per person-day) will also increase in the future as demand for their use increases relative to the world supply of coral reefs.

In addition, total use value is an under-estimate of total economic value because it is highly likely that some people have non-use economic value or passive economic value for SPAs and ERs. Non-use or passive economic use values include willingness of people to pay some amount simply to know that SPAs and ERs will be maintained in a certain condition, even though they never intend to use SPAs and ERs (existence value) or their willingness to pay to ensure that SPAs and ERs are maintained for future generations to enjoy (bequeath value). Another type of non-use value not accounted for here is “option value” or the amount people would be willing to pay to ensure that SPAs and ERs would be maintained in a condition suitable for their use some time in the future, even though they currently have not had a chance to use them. This latter value is like that of an insurance policy on future use, where there is uncertainty both about future use and future supply of the resource.

Table 2. SPA and ER use value: 2000-01.

Type of User	User Value Per Person-day ($)	Annual Person-days of Use	Annual Use Value (Millions $)
Visitors			
Diving[1]	$19.46	590,700	$11.495
Glass-bottom boat rides	$22.53	58,500	$1.318
Total	$19.74	649,200	$12.813
Residents			
Diving1	$9.25	593,400	$5.489
Visitors & Residents			
Diving1	$14.34	1,184,100	$16.984
Glass-bottom boat rides	$22.53	58,500	$1.318
Total	**$14.73**	**1,242,600**	**$18.302**

1. Diving includes snorkeling and scuba diving.

Comparative Importance-Satisfaction Ratings: SPA- and ER-Users vs. Non-Users
In the 2000-01 reef study, importance/satisfaction ratings were obtained for 25 natural resource attributes, facilities, and services. Here we compare measurements taken in 2000-01 for both residents and visitors; we further disaggregated these groups into SPA- and ER-users versus non-SPA- and non-ER-users. We did this for eight of the 25 items that are more directly or indirectly related to SPAs and ERs. The eight items included six natural resource attribute items and two natural resource facility items (Table 3).

<u>Importance Scores: Visitors</u>
Visiting SPA- and ER-users had higher mean importance scores than non-SPA- and non-ER-users for four of the eight items:

A. Clear Water (high visibility)
C. Many different kinds of fish and sea life to view
H. Parks and specially protected areas
K. Mooring buoys near coral reefs

Visiting SPA- and ER-users had a lower mean importance score than non-SPA- and non-ER-users for:

D. Many different kinds of fish and sea life to catch

This is as expected because catching fish and sea life is prohibited in SPAs and ERs.

<u>Importance Scores: Residents</u>
Resident SPA- and ER-users had higher mean importance scores than non-SPA- and non-ER-users for seven of the eight items, all except:

D. Many different kinds of fish and sea life to catch

Again, this is expected because catching fish and sea life is prohibited in SPAs and ERs. The difference from the result for visitors was that mean scores for item (D) were lower for SPA- and ER-users than non-SPA- and non-ER-users, but the difference was not statistically significant.

<u>Satisfaction Scores: Visitors</u>
Visiting SPA- and ER-users had higher mean satisfaction scores than non-SPA- and non-ER-users for three of the eight items:

C. Many different kinds of fish and sea life to view
F. Large numbers of fish
H. Parks and specially protected areas

All other differences were not statistically significant.

<u>Satisfaction Scores: Residents</u>

Resident SPA- and ER-users had a lower mean satisfaction score than non-SPA- and non-ER-users for only one item:

D. Many different kinds of fish and sea life to catch

All other differences were not statistically significant.

Table 3. Comparison of 2000-01 importance/satisfaction scores: SPA- and ER-users versus non-SPA- and non-ER-users.

	Visitors		Residents	
Item	Importance	Satisfaction	Importance	Satisfaction
Natural Resource Attributes				
A. Clear Water (high visibility)	+●	+	+●	ND
B. Amount of living coral on reefs	+	+	+●	-
C. Many different kinds of fish and sea life to view	+●	+●	+●	-
D. Many different kinds of fish and sea life to catch	-●	+	-	-●
E. Opportunity to view large wildlife (manatees, whales, dolphins, sea turtles)	-	+	+●	-
F. Large number of fish	-	+●	+●	-
Natural Resource Facilities				
H. Parks and specially protected areas	+●	+●	+●	+
K. Mooring buoys near coral reefs	+●	+	+●	+

● = statistically significant difference in mean scores at 0.05 or lower level of significance
+ = higher mean score, not statistically significant
- = lower mean score, not statistically significant
+● = higher mean score and statistically significant at 0.05 or lower
-● = lower mean score and statistically significant at 0.05 or lower
ND = no difference

Conclusions: Importance-Satisfaction Ratings

For most of the key attributes, both visitor and resident SPA- and ER-users had significantly higher importance scores than non-users. Visiting SPA- and ER-users had generally higher satisfaction scores than non-users with statistically significant higher scores for three key items: 1) Many different kinds of fish and sea life to view, 2) Large numbers of fish, and 3) Parks and specially protected areas. Resident SPA- and ER-users, however, had a mix of lower and higher satisfaction scores than non-users, but none of the differences was statistically significant.

Even though the SPAs and ERs have been in existence for a relatively short period, it appears that visitors already perceive them as relatively higher-quality areas. As of 2000-01, residents do not seem to perceive a difference in the SPAs and ERs versus the open areas of the FKNMS.

References

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2003a. Socioeconomic study of reefs in southeast Florida. Final Report October 19, 2001 as revised April 18, 2003 from Hazen and Sawyer to Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Conservation Commission and National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/Reefs/02-01.pdf

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2003b. Socioeconomic study of reefs in southeast Florida. Technical Appendix to Final Report October 19, 2001 as revised April 18, 2003 from Hazen and Sawyer to Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Conservation Commission, and National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/Reefs/PDF's/Tech/TechApp.pdf

Leeworthy, V.R., and J.M. Bowker. 1997. Nonmarket economic user values of the Florida Keys/Key West. Silver Spring, MD: National Oceanic and Atmospheric Administration and Athens, GA: U.S. Forest Service. http://marineeconomics.noaa.gov/SocmonFK/publications/97-30.pdf

Leeworthy, V.R., and P.C. Wiley. 1996. Importance and satisfaction ratings by recreating visitors to the Florida Keys/Key West. Silver Spring, MD: National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/SocmonFK/publications/96-27.pdf

Leeworthy, V.R., and P.C. Wiley. 1997. A socioeconomic analysis of the recreation activities of Monroe County residents in the Florida Keys/Key West. Silver Spring, Maryland: National Oceanic and Atmospheric Administration. http://marineeconomics.noaa.gov/SocmonFK/publications/97-18.pdf

Leeworthy, V.R., P.C. Wiley, and J. Hospital. 2004. Importance-satisfaction ratings five-year comparison, SPA & ER use, and socioeconomic and ecological monitoring comparison of results 1995-96 to 2000-01. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Ocean Service, Office of Management and Budget, Special Projects Division.

Economic Valuation of Marine Reserves in the Florida Keys as Measured by Diver Attitudes and Preferences: Implications for Valuation of Non-consumptive Uses of Marine Reserves

David Letson, Manoj Shivlani, Daniel Suman, and Kristin Kleisner (University of Miami, Miami, FL)

Goals
This study, funded by the Marine Fisheries Initiative, seeks to determine the value of a non-consumptive activity, diving, in marine reserves, as measured by contingent valuation and user attitudes, and to identify the factors that either enhance or reduce marine reserve value by: 1) evaluating the monetary value (and willingness-to-pay for) that divers place on marine reserves in the Florida Keys, 2) ranking the attributes offered by the marine reserves that enhance diver visitation and satisfaction, and 3) developing a matrix that matches diver preferences for marine reserves.

Methodology
The research team developed a field survey questionnaire that was tailored for each dive operator participating in the study to administer periodically to divers and snorkelers visiting marine reserves and general-use areas in the Florida Keys National Marine Sanctuary. The questionnaire contained questions on the following: 1) demographic and dive-specific background, 2) reason and details of trip, 3) expected and observed conditions at the sites visited, 4) willingness-to-pay for site visited, and 5) comparison to other sites. Please refer to the web site: http://www.rsmas.miami.edu/etc/dive-survey.cgi for a copy of the questionnaire.

More than 20 sites, including those within and outside marine reserves, were identified as part of the survey design, and 12 dive operators were contracted to participate in the study. Dive operation personnel administered surveys to divers and snorkelers returning from trips four times a month (depending on weather conditions). The survey period commenced in late 2002 and will extend into early 2004.

Additionally, a dive operator questionnaire was developed and administered using Lower Keys dive operations prior to implementation of the diver survey session. This questionnaire probed operators on economic aspects of their industry, trip profiles (including the importance of marine reserves as dive trip destinations), and their views on marine resource management.

Findings to Date
Based on totals (n = 564) through August 2003, or month 8 of the project, results indicate that users value marine reserves and multiple-use dive sites as centers of marine resource management and recreation. Findings also demonstrate that respondents generally view all dive sites favorably, in terms of their ecological and social conditions, suggesting the efficacy of local area management, as it relates to this user group. Finally, most divers and snorkelers report congruence between expected conditions and personal experiences, which may explain the high trip satisfaction ratings.

Most divers and snorkelers visiting the sites were 40 years old or younger (58%), and they traveled to the Lower Keys and Key West for over four nights (67%) to engage in multiple activities. Almost 60% took only one dive/snorkel trip while in the region, although 77% reported making a multiple-day trip. Most respondents (83%) either only snorkeled or had limited diving experience, and over 72% had been diving for five years or less. Only a fifth of the divers reported choosing their dive site destination; 80% visited sites selected by the dive operation. Of the respondents who chose their dive site, 58% visited a single location: Looe Key Sanctuary Preservation Area (SPA) in the Lower Keys.

The most popular activities reported were nonconsumptive, including marine identification (47%) and underwater photography (42%); consumptive activities such as spearfishing (5%) and lobster diving (17%) were less popular. Highest expectations for sites, reported in ranked means (scale was 1-5), were water clarity (mean = 1.69), to see different kinds of fish (1.69), and to see other large animals (1.82). Viewing rare organisms (2.57) and invertebrates (2.37) was less important to the respondents. Most observed means were close to expectations, with the exceptions of water clarity (observed = 2.25, expected = 1.69) and seeing rare animals (observed = 3.1, expected = 2.57). That is, most divers and snorkelers reported having their expectations met for seeing large fish, different kinds of fish, and large animals.

Over 90% of the visitors reported diving in areas that afforded excellent or reasonable spacing conditions, and only 5% complained of overcrowding at the dive sites. Accordingly, 73% stated that they would likely return to the site(s) visited. Almost half of the divers and snorkelers (45%) had previously been to a dive site in the Florida Keys, and the average time between trips was 2.7 years. Of that total, almost two-thirds (62%) felt that the current trip was better than the previous one, and an equal percentage (63%) ranked the current site above other areas visited outside the Florida Keys. Only 40% of the respondents were willing to pay for additional protection and exclusive access to the dive site visited, and the average willingness-to-pay was $9.61 (compared to $10.56 for those who were not willing to pay).

The results suggest that divers and snorkelers who use Lower Keys dive sites do so as part of a larger, multiple-activity trip. They are generally inexperienced users who are interested in mostly nonconsumptive activities and who expect to see large and diverse fauna at a clear, high underwater visibility dive site. Whereas most are not motivated to visit a single site, Looe Key SPA does attract considerable use from persons who report having learned about it from a variety of personal and literature sources. Dive sites, regardless of whether they are marine reserves or not, generally meet resource expectations, with the exceptions of viewing rare organisms and encountering clear water conditions. The experience leads to a willingness-to-pay by 40% of the users, who are willing to pay an additional $9.61 per person per year (ahead of operator fees, which can range between $25 and $60) for exclusive access to the site and its marine resources.

Socioeconomic Monitoring Program of Commercial Fishing Panels

Thomas Murray (Thomas J. Murray & Associates, Gloucester Point, Inc., VA)
Manoj Shivlani (Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL)
Bob Leeworthy (NOAA/NOS/Special Projects, Silver Spring, MD)

Goals

The Socioeconomic Monitoring Program (SMP), funded by the National Oceanic and Atmospheric Administration (NOAA), concerns the human uses dimension in the FKNMS. It focuses on the commercial fishing industry in the Florida Keys, effects of FKNMS regulations on commercial fisheries, and additional impacts to the local economy.

Methodology

The program tracks user attitudes, perceptions, and beliefs with regard to FKNMS regulations and strategies. The program commenced in 1998, following implementation of the FKNMS management plan in 1997, and has tracked the commercial fishing industry for five years (1998-2002).

The SMP adopts an integrated approach to monitor uses and effects of FKNMS regulations by utilizing field surveys and existing fishery information. Four panels, based on their fishery or location, represent the fishing communities monitored. The panels consist of:: Tortugas Ecological Reserve (TER) Panel, Western Sambo Ecological Reserve (WSER) Panel, Marine Life Collectors Panel, and the General Fishery Panel. Fishers on the TER and WSER panels represent those users who fished the Dry Tortugas and Sambos regions, respectively, prior to their implementation as fully protected ("no-take") marine zones. The marine life collectors consist of fishers located across the Florida Keys who had collected tropical fish and invertebrates in the smaller fully protected marine zones (designated as Sanctuary Preservation Areas and Special-Use Areas) prior to their implementation. The general panel serves as a control, to determine whether effects may result from factors other than FKNMS regulations.

Each panel is comprised of 5-9 fishers with long-standing, full-time experience in the fishery, and fishery panel members are identified from previous research efforts and experience in the region. Together, the members from each panel provide annual economic and social data, as well as spatial use information since year three.

Findings to Date

Information collected in the first five years (Table 1) suggests that harvest totals and net earning increased or remained stable in the first three years but declined in the fourth year with some recovery in the most recently surveyed year (2001-2002).

TABLE 1: PANEL COSTS AND RETURNS, 1997-2001

PANEL	$ Costs/Returns	’97-’98	’98-’99	’99-’00	’00-’01	’01-’02
TER	Harvest total	$196,090	$215,778	$189,299	$149,759	$145,611
	Net earnings	61,909	38,118	47,139	29,064	29,679
	Vessel cost	163,333	218,333	235,000	190,000	217,113
	Gear cost	40,975	43,750	39,571	34,750	48,286
WSER	Harvest total	97,725	129,666	133,149	81,464	91,108
	Net earnings	27,725	45,913	44,390	22,299	24,204
	Vessel cost	138,889	140,500	185,500	146,857	171,333
	Gear cost	69,899	79,766	98,718	76,000	88,667
Collectors	Harvest total	48,200	N/A	31,958	30,109	37,382
	Net earnings	N/A	N/A	19,330	12,022	21,500
	Vessel cost	40,750	N/A	56,000	44,167	53,000
	Gear cost	17,750	N/A	17,300	15,417	18,500
General	Harvest total	96,523	113,379	129,557	92,252	95,883
	Net earnings	30,806	37,577	39,778	20,970	20,856
	Vessel cost	70,000	70,000	77,167	52,143	60,833
	Gear cost	$47,367	$63,416	$67,800	$56,243	$65,617

Importantly, the information collected suggests that extra-Sanctuary factors may contribute strongly to interannual fishery harvests and production. For example, the higher vessel and gear costs exhibited by the WSER panel between the 1998-99 and 1999-2000 seasons were related to lost gear resulting from *Hurricane Georges* in 1998 rather than initial implementation of fully protected marine zones. The final reporting year shows that with the exception of the TER panel, all panels reported gross and net earnings higher than the previous year, but below their five-year average. The Collector’s panel has experienced increases in gross and net income for the past two seasons. Overall lower levels of profitability within the three commercial fishing panels (TER, WSER, and General) since 1998-1999 reflect the overall downturn in the spiny lobster and stone crab fisheries. This is thought to primarily relate to a decline in the major crustacean fisheries in the region (spiny lobster and stone crab) rather than to displacement from fully protected marine zones. This view is reinforced when the TER and WSER panels’ data are compared to those of the general, or control, panel. All three panels experienced major decreases in earnings and harvest totals from previous years. However, it should be noted that there might be local impacts of the fully protected marine zones that lead to higher operating costs (e.g., displacement, crowding), but that those are not reflected in the inter-panel analysis.

User attitudes, beliefs, and perceptions concern the opinions of all panel members as they relate to the FKNMS and its zoning strategy, and the SMP has collected such information since its inception in 1998. The information is compared with baseline attitudes, beliefs, and perceptions from a study conducted in 1996 (Milon et al, 1997), and the present research determines whether the opinions of fishermen have changed over time.

Most recent findings suggest that most panel members (94%) do not believe that the fully protected marine zones have increased or replenished stocks in the region, and none of the fishers believes that his group has been the primary beneficiary of the zoning strategy. These statistics are similar to results from a 1995-96 study (Milon et al., 1997) conducted in the region, where 60% of the 340 commercial fishers interviewed reported that fully protected marine zones would not increase fish stocks in the Florida Keys, and 90% felt that commercial fishers would not be the primary beneficiaries of the zoning strategy. Almost two-thirds of the panel members do not favor the establishment of the current zoning plan (compared to 86% in the 1995-96 study), and 77% would oppose further zones in the Sanctuary (compared to 64% in the 1995-96 study). Finally, as in the 1995-96 study where 78% of commercial fishers interviewed opposed Sanctuary designation, a majority of the respondents (68%) remains against the establishment of the Sanctuary.

Since its third year, the SMP has collected spatial data from panel members. That information shows that there are major differences in areas utilized, by species, gear type, and home-port (Rudders and Shivlani, 2003). Preliminary results, from all three seasons analyzed, suggest that panel member fishing areas in the FKNMS are largely determined by proximity to home-ports, with the exception of the Dry Tortugas fishery and certain species (stone crab and king mackerel, in particular, and spiny lobster, occasionally). Also, fishing is quite prevalent around fully protected marine zones, and many of the species (especially lobster, reef fish, and marine life) are fished or collected near the boundaries of these zones. Also of importance in the three-year comparison has been the finding that any single year description only represents a “snapshot” of spatial fishing effort. Due to changes in regulatory conditions, financial solvency, and environmental conditions (and perhaps a complex combination of all three factors), fishers decide to expand or contract their fishing areas and activities. Figures 1-3 show total panel member use in the FKNMS for the period 1999-2002.

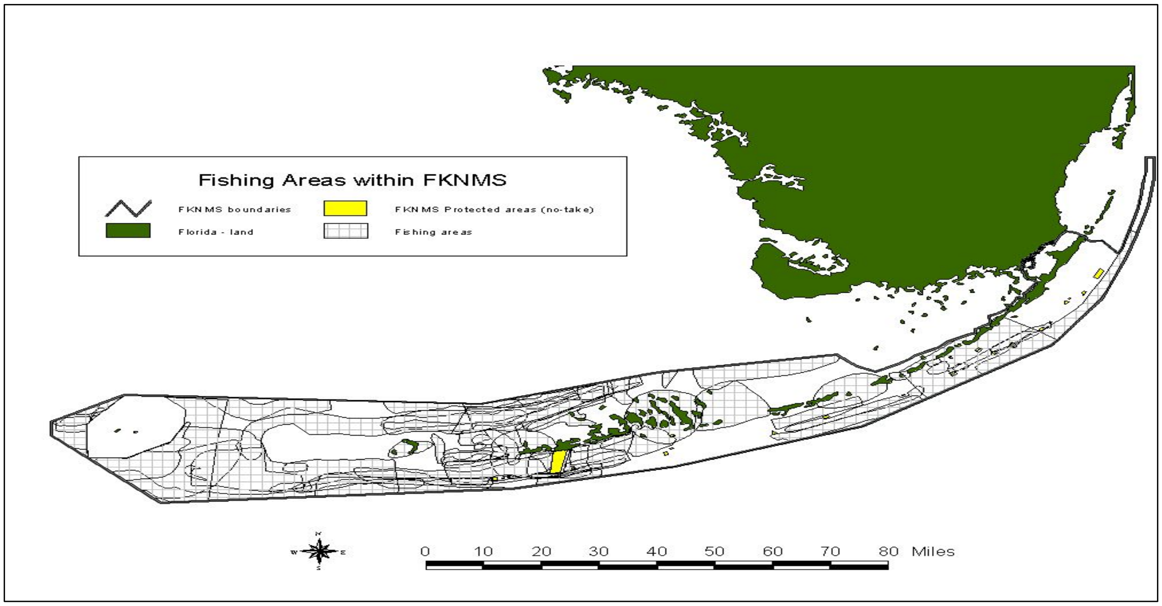


Figure 1. Fishing areas in the FKNMS: 1999-2000.

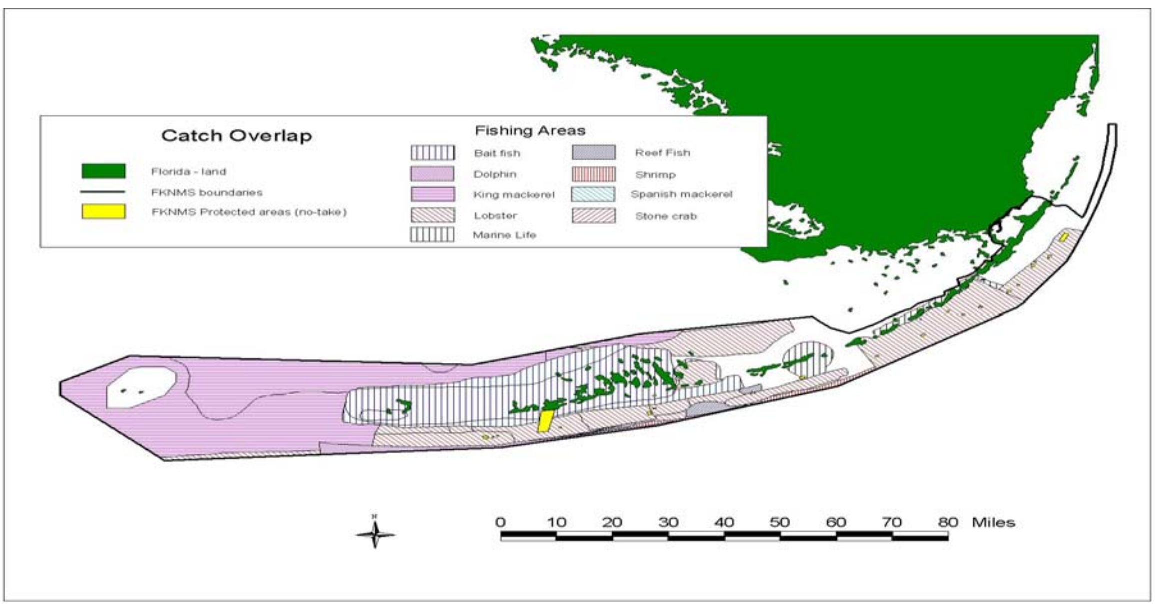


Figure 2. Fishing areas in the FKNMS: 2000-01.

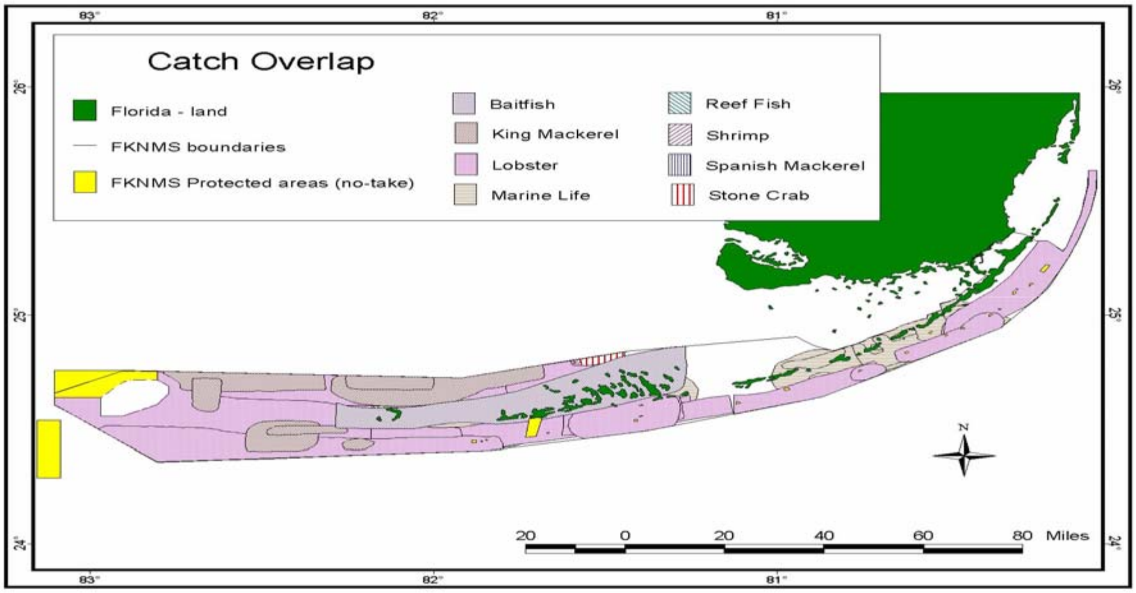


Figure 3. Fishing areas in the FKNMS: 2001-02.

References

Milon, J. W., D. O. Suman, M. Shivlani, and K. A. Cochran. 1997. Commercial fishers' perceptions of marine reserves for the Florida Keys National Marine Sanctuary. Florida Sea Grant Technical Paper-89.

Rudders, D., and M. Shivlani. 2003. Geospatial Information Systems (GIS) analysis of Florida Keys National Marine Sanctuary fishing panels. World Wide Web Document. URL: www.marineeconomics.noaa.gov/SocmonFK/publications/CommFish20030409-2.pdf.

Partnership Projects with NOAA National Centers for Coastal Ocean Science

Assessing Coral Health in the Florida Keys National Marine Sanctuary Using a Molecular Biomarker System

Cheryl M. Woodley (NOAA/NOS Center for Coastal Environmental Health and Biomolecular Research and Medical University of South Carolina, Charleston, SC)
Eric R. Lacy (Medical University of South Carolina, Charleston, SC)
John E. Fauth (University of Central Florida, Orlando, FL)
Craig A. Downs (EnVirtue Biotechnologies, Inc, Winchester, VA)
Judith Halas (Environmental Moorings International, Key Largo, FL
Pamela Hallock Muller and Elizabeth Fisher (University of South Florida, St. Petersburg, FL)
Richard Curry (Biscayne National Park, Homestead, FL)
John Halas (Florida Keys National Marine Sanctuary, Key Largo, FL)

Goals

We have designed an integrated Cellular Diagnostic System (CDS) to diagnose whether an organism is stressed and to identify the likely stressor(s) (e.g., heat stress, pesticides, and pathogens). Our goals are to: (1) use the CDS to characterize the health of a coral reef ecosystem in the Florida Keys; (2) verify that the CDS can detect and characterize subtle and chronic effects of environmental stressors on this ecosystem; (3) determine if point-source pollutants or global climate changes (e.g., increased ocean temperatures or UV-B radiation) are stressing coral reef ecosystems; (4) compare the precision, sensitivity, and prognostic capabilities of the CDS to those of traditional measures of ecosystem health, and (5) encourage participation and understanding of the general public, scientific, industrial, and managerial communities in using marine biotechnologies to assess and manage the health of coral reef ecosystems.

Methods

The methods being employed range from established protocols for community-scale assessment (i.e., the AGRRA protocol of Ginsburg et al. 2000), foraminiferal condition (i.e., Hallock Muller et al. 1995), and CDS analysis (previously known as MBS) (Downs et al. 2000, 2001), to methods adapted to monitor coral lesions and sedimentation.

Cellular Diagnostics

The Cellular Diagnostic System is an ELISA-based assay system, specifically used to measure changes in cellular parameters, and allows assessment of cellular-physiological condition, monitoring of cellular stress responses, identification of putative stressors, and provision of a prognosis. Cellular diagnostics uses a systematic approach to quantifying cellular and biochemical responses of defined biomarkers of exposure, effect, and susceptibility based on their functionality within a cell and integrate, or profile, those responses into a diagnosis and subsequently a prognosis. Knowledge of biomarker function helps describe how alterations in the behavior of a single cellular parameter or set of cellular parameters (biomarkers) may affect overall cellular operation or performance (Downs 2004). We use this information to distinguish cellular diagnostics from biomarkers, which are biological response elements without known functional association.

The cell is a dynamic system comprised of both macro- and micro-structures and processes. Many of these sub-cellular processes are key metabolic pathways and cellular structural components that are essential for maintaining cellular operations, homeostasis, and cell functionality. These cellular metabolic pathways and structural operations can be divided into categories or sub-systems of cellular integrity and function, which can be further defined by discrete parameters (Table 1). The behavior of these components and processes defines the physiological condition of the cell. Stressors affect ecosystems by overwhelming allostatic defenses (i.e., the continuous process of adaptation experienced by the host in the face of potentially stressful challenges; Seeman et al. 1997) at lower levels of the biological hierarchy — specifically, molecular, cellular, and organism-level homeostatic processes. As the *allostatic load* (i.e., the wear and tear experienced as a result of repeated cycles of allostasis; McEwen et al. 2003) increases there is an overall accumulation of negative effects of adaptation to various challenges and adverse environments -- superimposed on such things as genetic predisposition and development. Thus stressors (allostatic load) reduce individual fitness, alter demographic patterns, and affect the structure, function, and resilience of coral reef communities. Changes in cellular and molecular parameters may precede ecosystem-level responses to chronic stress by days, months, or years. Measuring changes in these cellular parameters allows: (1) determination of cellular-physiological condition of an individual or population; (2) identification of putative stressors, either by direct measurement of the stressor or by profiling stressor-specific effects; and (3) forecasting higher-order behavior based on an understanding of cellular-level processes (Downs 2004). Cellular diagnostics provides a new approach to health assessment, though its fundamental tenets are rooted on concepts and methodologies central to medical diagnostics and epidemiology.

Table 1. Categories and Parameters of Cellular Integrity and Homeostasis

Genomic integrity – the ability of the genomic process to maintain a functional state. Parameter assayed in this project: Ogg1-nuclear.

Protein metabolic condition – the process of protein synthesis, protein maturation, and protein degradation. Parameters assayed were: Hsp 60 (cnidarian and dinoflagellate), Grp75 (Mortalin), Hsp70 (cnidarian and dinoflagellate), Hsp90, ubiquitin, and ubiquitin activase.

Xenobiotic detoxification – the process of preventing or reducing the adverse (toxic) effects of exposure to a xenobiotic. Parameters assayed were: glutathione-s-transferase, MDR, CYP P450 2 class, CYP P450 3 class, and CYP P450 6 class.

Metabolic integrity – the process of a cell in maintaining a differentiated state from its environment and is the product of sub-processes or 'metabolic' pathways. Parameters assayed were: (20) ferrochelatase, Protoporphyrinogen IX oxidase, heme oxygenase 1, mitochondrial small heat-shock protein, and chloroplast small heat shock protein.

***Oxidative damage and response* -** the process of maintaining a viable condition in an oxygen-laden environment. Parameters assayed were protein carbonyl, catalase, glutathione peroxidase, Mn superoxide dismutase, and Cu/Zn superoxide dismutase.

Endocrine modulation – parameters indicative of endocrine disruption include aspects that focus on classical endocrine systems besides changes in reproductive structure. Endocrine/reproduction parameters included vitellogenin level in males.

Lesion Regeneration
Coral lesions (i.e., partial mortality) of tagged corals (*Montastraea annularis* complex) were monitored quarterly (March/April, June, August/September, and October/November) in 2001 and 2002 and again in February 2003. A lesion was defined as an area on the colony with no live coral tissue. Lesions created by the biomarker sampling were approximately 2 cm^2 and should regenerate under non-stressful conditions (Meesters et al. 1997). To monitor lesions, each lesion was photographed using a Nikonos V camera with a close-up adapter. Photographs were scanned to digital images, and the area and perimeter of the lesions were calculated using image analysis software. These data will be used to determine whether correlations exist between coral lesion regeneration rates and molecular-scale responses of individual coral colonies providing quantitative indicators of stresses. Data on water temperature, nutrient levels, foraminiferal populations, and sedimentation will then enable us to determine if these factors correlate with changes in lesions and with stress levels quantified by the CDS. The hypothesis being tested is that a coral, which the CDS indicates to be more stressed, will be less likely to regenerate than a coral that CDS indicates to be less stressed.

Findings to Date
Our results indicate that this technology can be used to characterize coral health in defined areas of the Florida Keys (Goal 1), distinguish between global-level stressors (e.g., El Niño/La Niña effects) and local-level stressors (e.g., agricultural runoff) (Goals 2 and 3), and help predict the condition of corals several months before more obvious symptoms appear (e.g., coral bleaching or coral death) (Goals 3 and 4). Additionally, comparisons of coral lesion healing with biomarker response have shown significant correlations between the level of biomarker response (representative of the cellular physiological status) and measures traditionally used to assess ecosystem health (Goal 4). These results support our hypothesis that a coral that the CDS indicates to be more stressed will be less likely to regenerate than a coral that CDS indicates to be less stressed.

To build on results from 1999 and 2000, a two-year study (2001-2002) was conducted to test “proof of concept” for the efficacy of CDS in assessing coral reef ecosystem health. This study included two sites in Biscayne National Park (BNP) and six sites in the Florida Keys National Marine Sanctuary (FKNMS). Our design expanded sampling from just coral tissue (*M. annularis* complex), to include snails (*Coralliophila abbreviata*) and fish (white grunt: *Haemulon plumieri* and bicolor damselfish: *Stegastes partitus*). We also included a coralline green alga, *Halimeda opuntia,* initially; however, technical difficulties with protein extracts prevented analysis.

The cumulative results for 2001 and 2002 showed that this technology can be used to detect changes in the physiological condition of corals, snails, and fish and provided evidence for the type of stressor(s) that were responsible for these changes. Also included were traditional measures of coral ecosystem health, foraminiferal condition indexing, and an intermediate biomarker that integrates a number of cellular processes (lesion regeneration). These parameters were supportive and correlated with measures obtained from cellular physiological parameters. In general, our findings showed evidence for different stressors at different locations at different times and evidence that multiple stressors were responsible for physiological responses being observed. In some locations this meant healthy corals able to cope with the stressors and in other locations, coral death (loss of all living tissue). More specifically, white grunt profiles showed that these fish were experiencing xenobiotic exposures, particularly at Alina's Reef in BNP, while in 2002 at both Alina's Reef and East Bache Shoals these fish exhibited profiles that supported an endocrine disruption occurring as a result of toxicant exposures. A profile supporting endocrine disruptor exposure as well as oxidative stress was exhibited in bicolor damselfish, particularly in 2002; however, fish with these profiles were not limited to BNP. Snails appeared to be a good indicator of coral reef health. They showed little evidence of stress in 2001 while in 2002-2003 their profiles at our 6-m depth site in the FKNMS were consistent with exposure to an endocrine disruptor. In general the coral, *Montastraea annularis*, at Algae Reef, White Banks Dry Rocks, and our Key Largo 3-m depth sites, appeared to be physiologically stable; however, it did show increased stress compared to coral located at Dry Tortugas. In contrast, corals at the two reefs in BNP (Alina's Reef and East Bache Shoals) and at the 6-, 9-, and 18-m depth sites (Sites 2-4) in the FKNMS showed elevated levels of stress and overall poor physiological health. By February 2003, colonies at the 9-m site showed heavy algal overgrowth and two colonies with very little live tissue remaining. At the 18-m site colonies appeared to be dying and one colony had lost all living tissue. The trend over the two years of sampling was a general decline at the 9- and 18-m sites (Sites 3 and 4) with at least one colony completely dying.

In general, responses varied throughout the year with the winter months, late October through March, appearing more stressful, with summers less stressful. This is in contrast to 1999, which was a year with unusually high sea surface temperatures. The profiles obtained from 2000 through February 2003, we believe, were reflective of local conditions, and the physiological profiles of each of these trophic levels provided evidence of multiple anthropogenic stressors impacting coral reef ecosystem health.

Our findings were presented (Goal 5) to constituent groups in March 2002 and January 2004 including state and federal resource managers, coral biologists, and representatives from the general public who have been encouraged to offer input and collaborations on this and related projects.

Results and Data

Objectives 1-3

The Cellular Diagnostic System (CDS) was developed to focus a comprehensive array of biotechnologies on the diagnosis of a variety of ecosystem health issues; however, for this study we specifically tailored it to coral physiological health and discerning the causes of coral reef system declines (Downs et al. 2000; Woodley et al. 2001). In our initial studies, we specifically applied the CDS to corals in the Florida Keys and demonstrated that the CDS could distinguish whether a local coral population of *Montastraea annularis* was being stressed by a global stressor (e.g., high sea-surface temperatures; Fig. 1) or by a stressor that was local in nature (Fig. 2). In conjunction with other technologies and monitoring methods, this biotechnology was able to identify potential stressor(s) responsible for the decline (Fig. 3). The CDS also possessed the ability to predict the progression of a health condition based on key diagnostic markers (Fig. 4). In 2001 and 2002, we expanded our studies to address whether the CDS could also be used to assess the health of other reef organisms (snails and fish) and whether CDS evaluation of members of different trophic levels within a coral reef ecosystem could be used to assess overall ecosystem health.

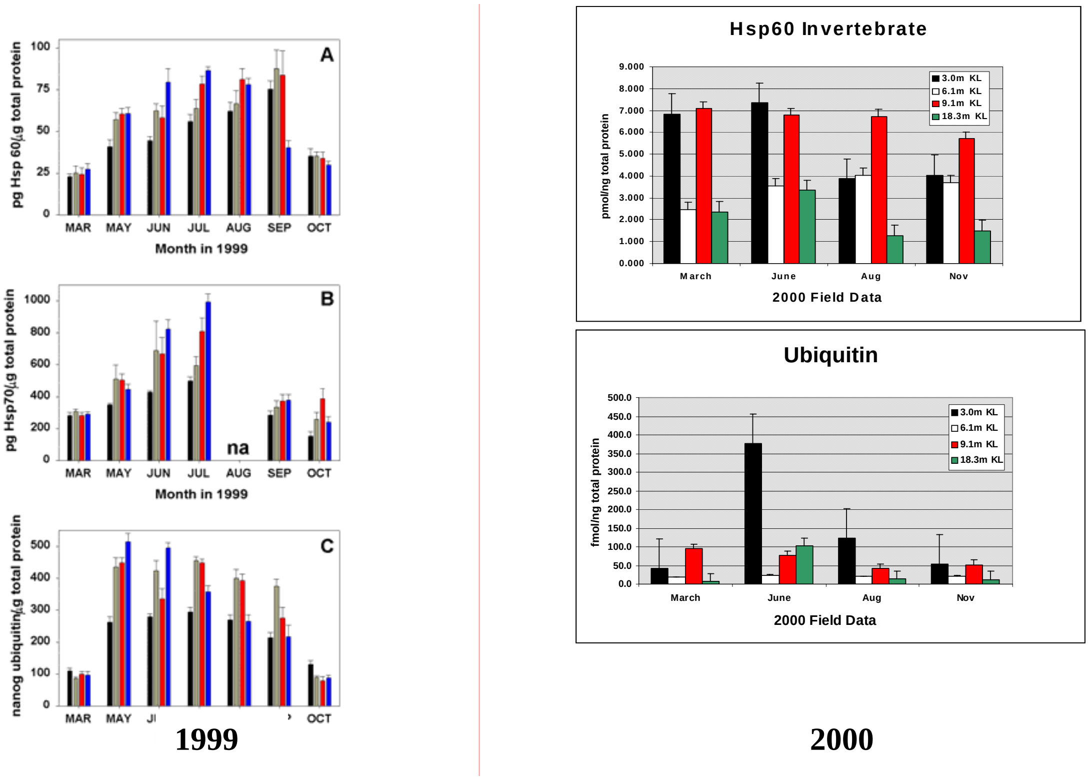
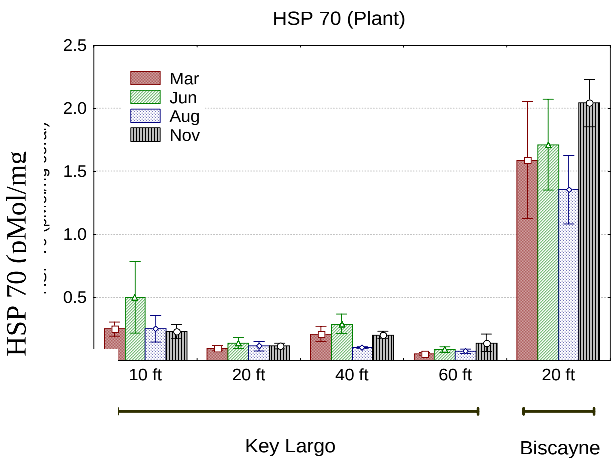
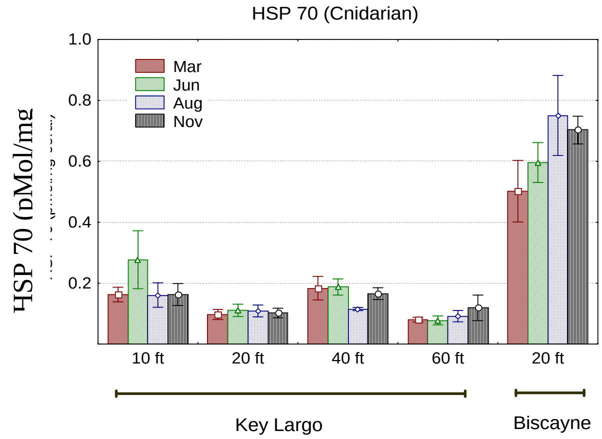


Figure 1. The same coral colonies from four sites at different depths were sampled on a monthly basis in 1999 and a quarterly basis in 2000**.** Hsp60 reflects chaperonin levels in the scleractinian; mean concentrations varied significantly with depth, month, and the depth x month interaction in 1999 (repeated measures MANOVAs: all $F > 2.56$, $P < 0.02$). Ubiquitin levels reflect the rate of protein degradation, which varied significantly with depth, month, and the depth x month interaction (repeated measures MANOVA: all $F > 8.80$, $P < 0.0001$). Bars show untransformed mean ($\pm$ 1 SE) biomarker concentrations at each depth: for 1999 panel, black = 3.0 m, grey = 6.1 m, red = 9.1 m, and blue = 18.3 m. Sites are from a four-mile-long transect off the eastern shore of Key Largo.

In Fig. 1, *M. annularis* scleractinian Hsp60 and ubiquitin data from the 1999 sampling project can be diagnostically interpreted as follows: the corals, at all four depths, were experiencing a protein-denaturing stress. This was indicated by a positive correlation between increased ubiquitin levels (a key component of a pathway for degrading 80% of the proteins in the cell) and abnormally high sea surface temperatures that peaked in the months of July and August (Downs et al. in review a). Hsp60 (for description of function, see Downs et al. 2000) data in 1999 corroborated this diagnostic interpretation. Though the extent of cellular damage differed significantly with depth, the data supported the argument that coral cellular damage at all four sites was the result of a global stressor (La Niña sea-surface temperature effects).





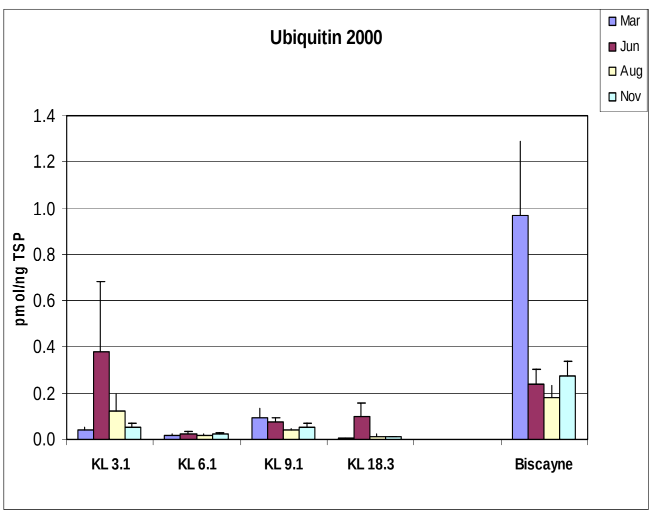


Figure 2. Data from 2000 field collections. Hsp70 is a ubiquitous chaperone, necessary for life. It functions to fold newly synthesized proteins into their active state and refold denatured proteins (resulting from a stressor) into functional enzymes. If a protein is severely damaged and cannot be refolded into a functional enzyme, it must be degraded. Protein degradation occurs mostly through the ubiquitin-proteolytic pathway. Damaged proteins are conjugated with ubiquitin, which designates to the cell that this specific protein is to be degraded. We have developed individual assays that are specific for the Hsp70 homologues found in both the dinoflagellate and scleractinian. Key Largo sites are the same as in 1999. Biscayne site is a patch reef found in southern reaches of Biscayne National Park, 15 nautical miles north of the Key Largo depth transect.

In 2000, the patterns of both parameters were radically different than those observed in 1999 and were not correlated with sea-surface temperatures (Woodley et al. in prep.). In March 2000, corals at 3-m depth were not experiencing a protein-denaturing cellular condition; however, they were experiencing non-adverse changes in mitochondrial function. In June 2000, corals at the 3-m site showed signs of cellular stress, which adversely affected mitochondrial function. These diagnostic interpretations for both 1999 and 2000 were corroborated by other diagnostic biomarker data. In summary, the cellular stress experienced by corals at all four sites in 1999 was the result of a global stressor as opposed to a local stressor at the 3- and 9-m sites in 2000 (and the stressor was different for these two 2000 sites – Woodley et al. in prep.). In 2000, using only three diagnostic markers (out of 24 biomarkers assayed for each coral sample), we could determine that a coral reef site in Biscayne National Park (BNP) was experiencing a severe cellular stress that was most likely generated by an electrophilically modifiable xenobiotic (e.g., a fungicide: an organometalloid, endosulfan) (Fig. 2 and 3). The extremely high level of ubiquitin indicated high rates of protein turnover. This interpretation was corroborated by five other cellular biomarkers. The level of ubiquitin in March 2000 at the BNP site has been suggested to be near the maximal threshold capacity for this coral species – massive cellular deterioration was beginning to occur and coral death could be predicted (Downs and Woodley in prep.). In August 2000, significant and punctuated coral coverage loss at the BNP site was observed – no observable coral coverage loss was observed in March 2000. This partially unidentified stressor adversely affected both scleractinian and dinoflagellate cellular physiology (Fig. 2). Data presented in Fig. 3 can be interpreted as follows: corals at the BNP site were responding to a xenobiotic stressor and the response pathway included a mono-oxygenase catalytic reaction at the site of olefinic double bonds of the xenobiotic, the conjugation of glutathione to the xenobiotic by glutathione-s-transferase, and cellular exclusion of the GSH-conjugated xenobiotic by a P-glycoprotein 140/160 pump action (a.k.a. MDR: multi-drug resistance gene) (Woodley et al. in prep.; Downs et al. in prep. b; not all data shown for this interpretation).

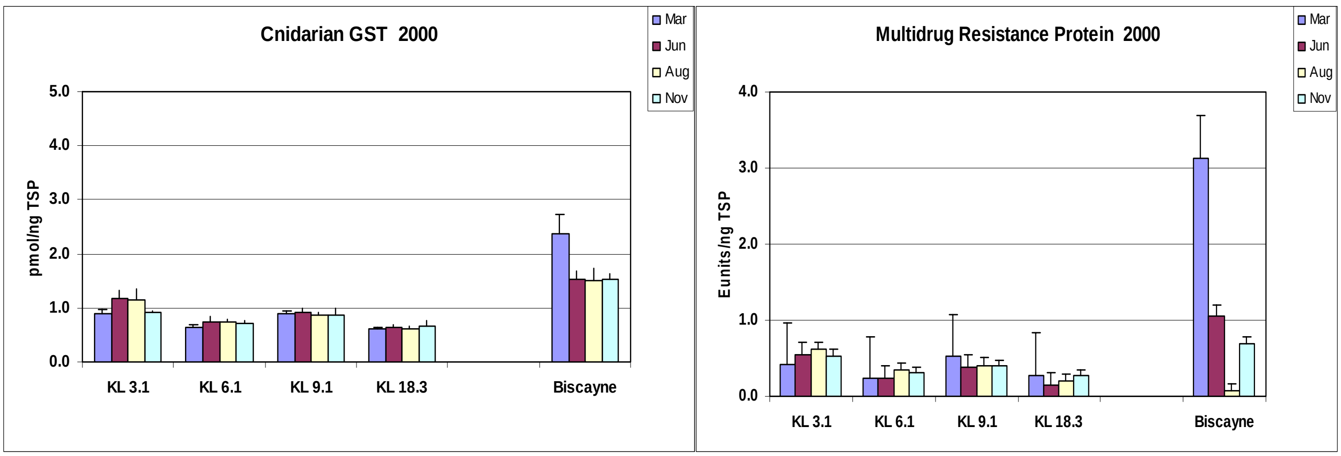
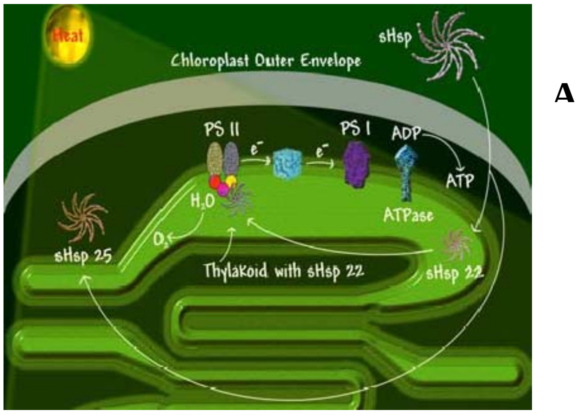
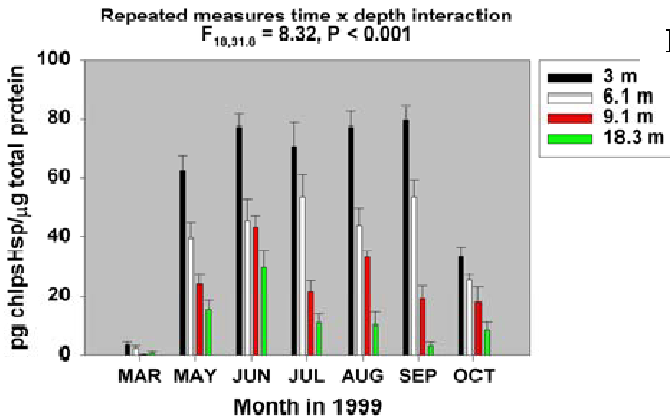


Figure 3. Data from 2000 field collections. GST Invertebrate = scleractinian homologues of glutathione-S-transferase. GST is an enzyme that will conjugate a xenobiotic with reduced glutathione so that the xenobiotic can easily be managed by the cell. MDR = P-glycoprotein 160, a member of the ABC family of proteins that is up-regulated when an organism has been exposed to specific classes of xenobiotics. Its function is to detoxify the cell of xenobiotics by pumping these xenobiotics out of the organism. Site locations are the same as described in Fig. 2.





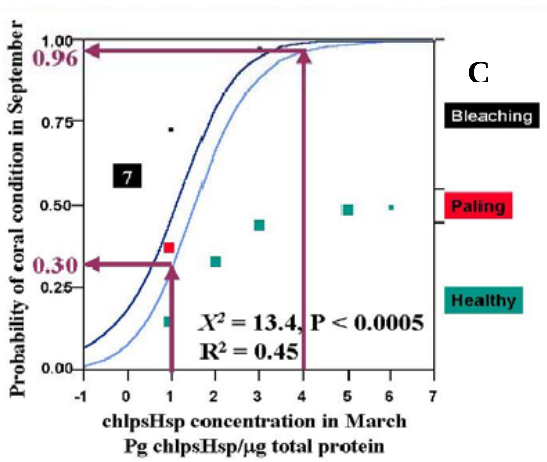


Figure 4. Panel A – Function of the chloroplast small heat-shock protein (Chlpshsp). This protein is only induced when photosystem II is being damaged. It is a major adaptation of photosynthesis against heat stress, oxidative stress, and photoinhibition (Downs et al. 1999a, b). Panel B – Levels of ChlpsHsp in dinoflagellate of *M. annularis*. Coral samples and sampling scheme the same as in Fig. 2. (Downs et al. in review). Panel C- Logistic regression analysis of probability of the level of chlpsHsp in March to predict coral bleaching in September when sea surface temperatures reached 31ºC in August (Fauth et al. in prep.).

In 2001 we continued to detect responses that indicated local stressors. Using a principal component analysis (Fig. 5), the following patterns emerged. The Key Largo 3-m site differed greatly from all the other six sites. The large upward spike in October suggested that a response to metals dominated over a xenobiotic response (data not shown). The Key Largo 6-m site had a similar profile, only not as pronounced. One possible explanation is that sedimentation and runoff may have contributed to these responses. Although we cannot unambiguously identify the specific stressor at this time, we know that it dramatically affected the algal component of the coral, as indicated by markers specific for the chloroplasts and algal mitochondria, and that it was likely associated with runoff and rainfall events. The effect of sedimentation will be tested using sedimentation data collected from sediment traps. In addition, except for the most offshore site, all sites had negative PC2 scores in March, suggesting that responses to a xenobiotic predominated over a metal stress. Again, one possible explanation is pesticide runoff. This will be further investigated by examining whether correlations exist between cellular diagnostic parameter levels and water chemistry parameters (chlorophyll a and/or pigments).

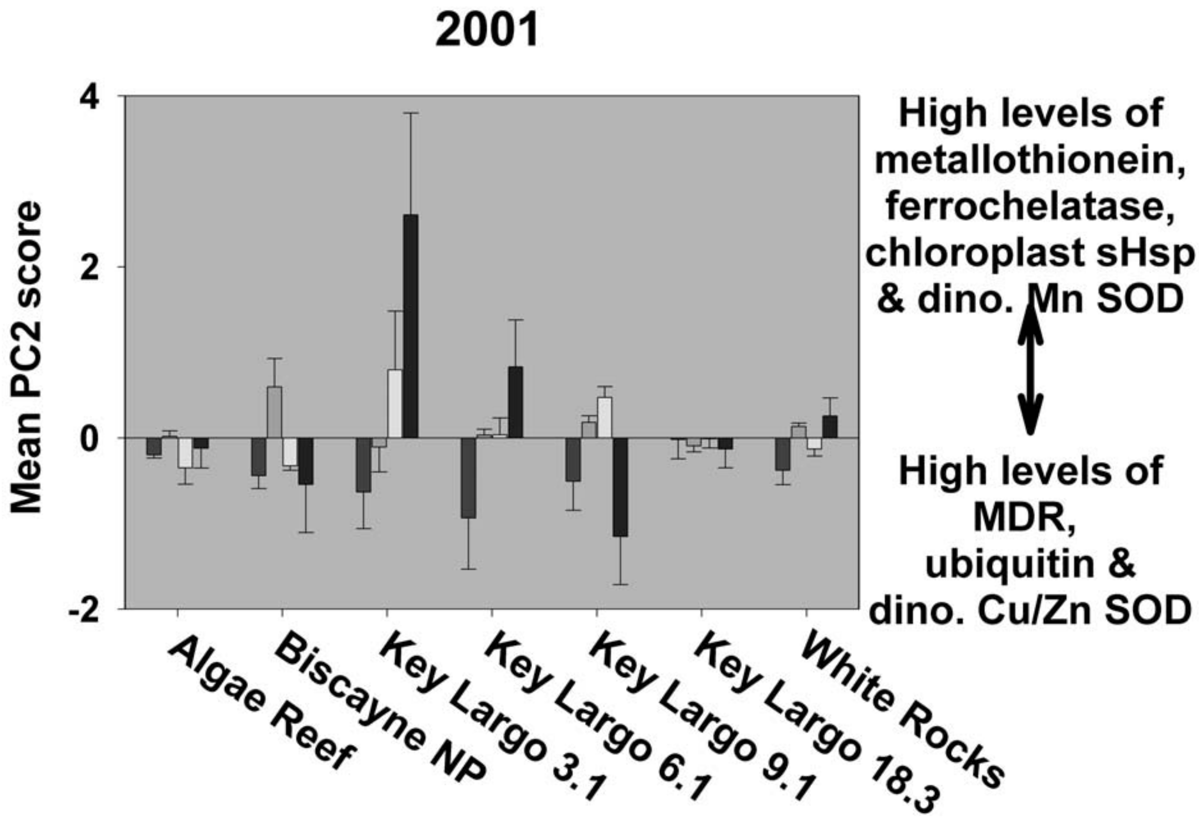


Figure 5. Results of the principal component analysis conducted on data from seven sites during different sampling periods; red = March; green = June; yellow = August; blue = November).

Metabolic Condition

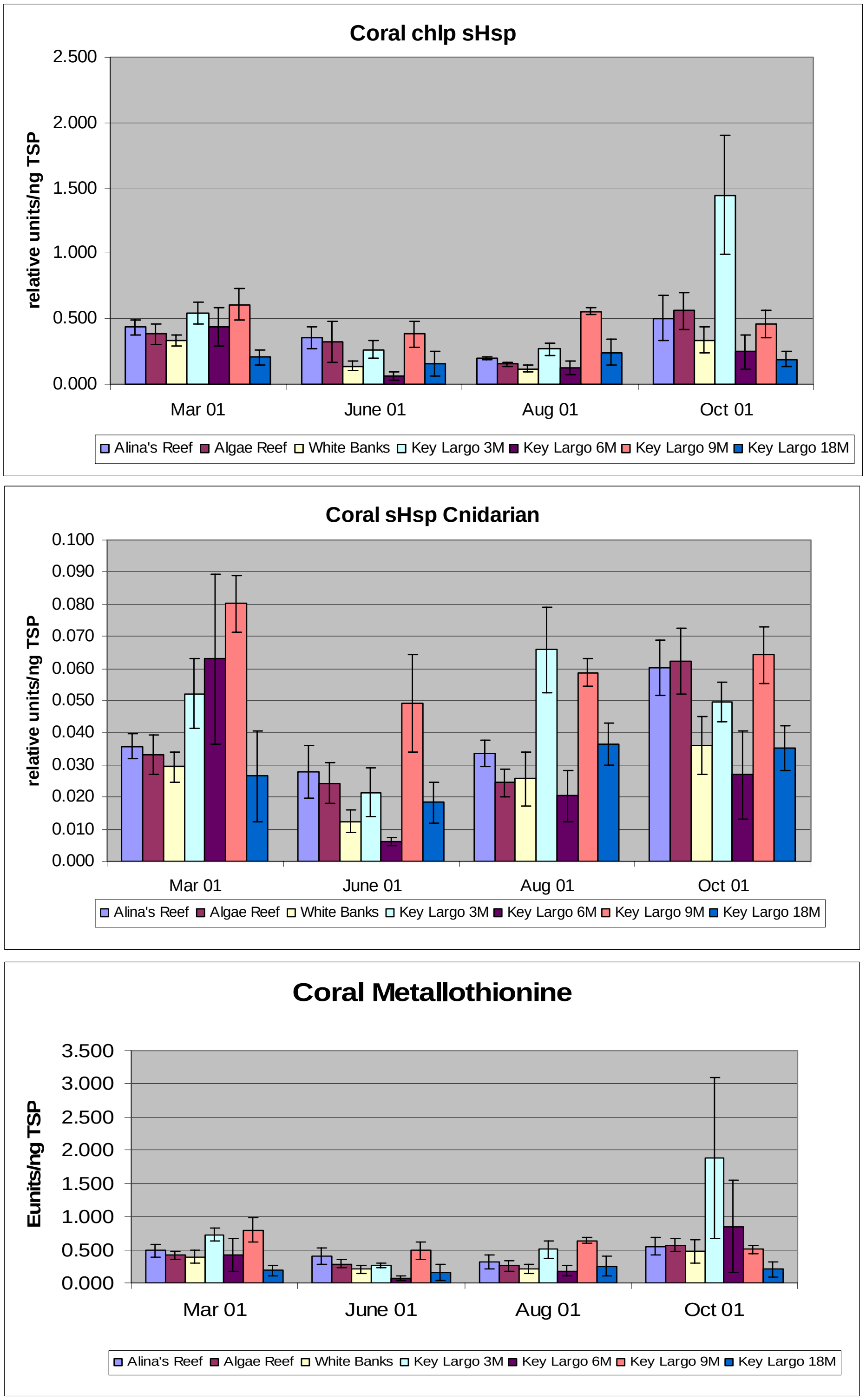
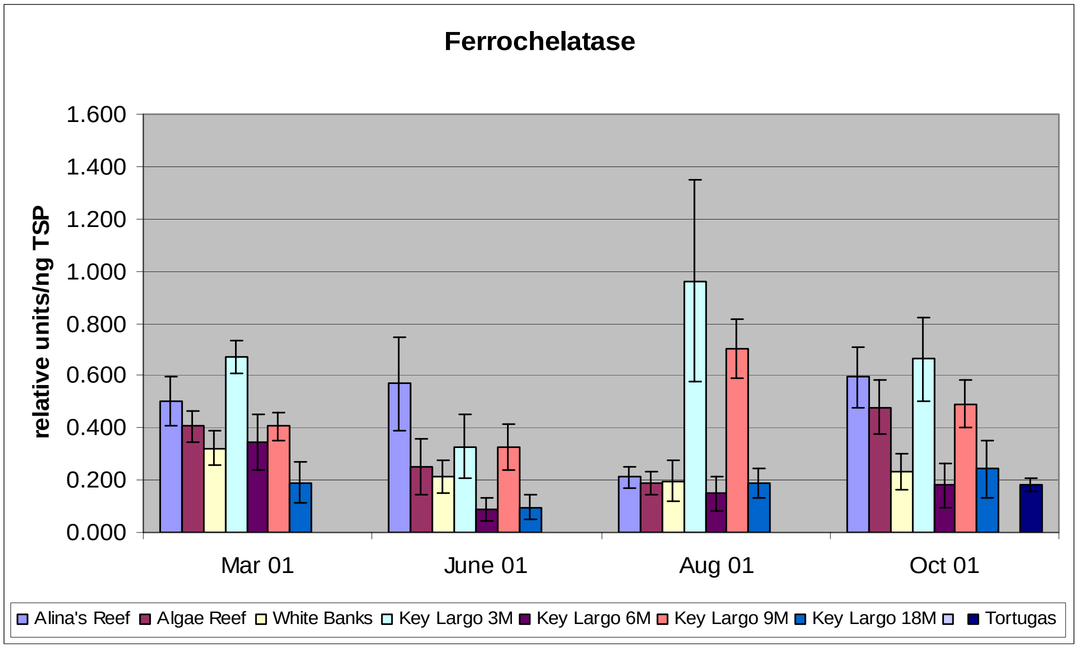


Figure 6. Metabolic condition of corals 2001.



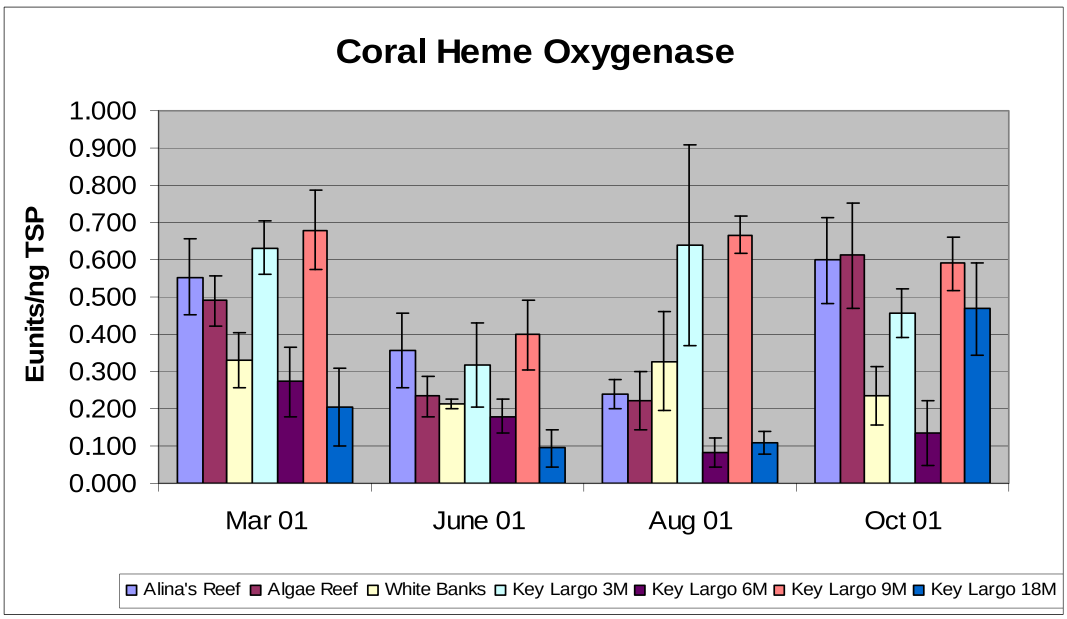


Figure 6. Metabolic condition of corals 2001 (cont'd).

Protein Metabolic Condition

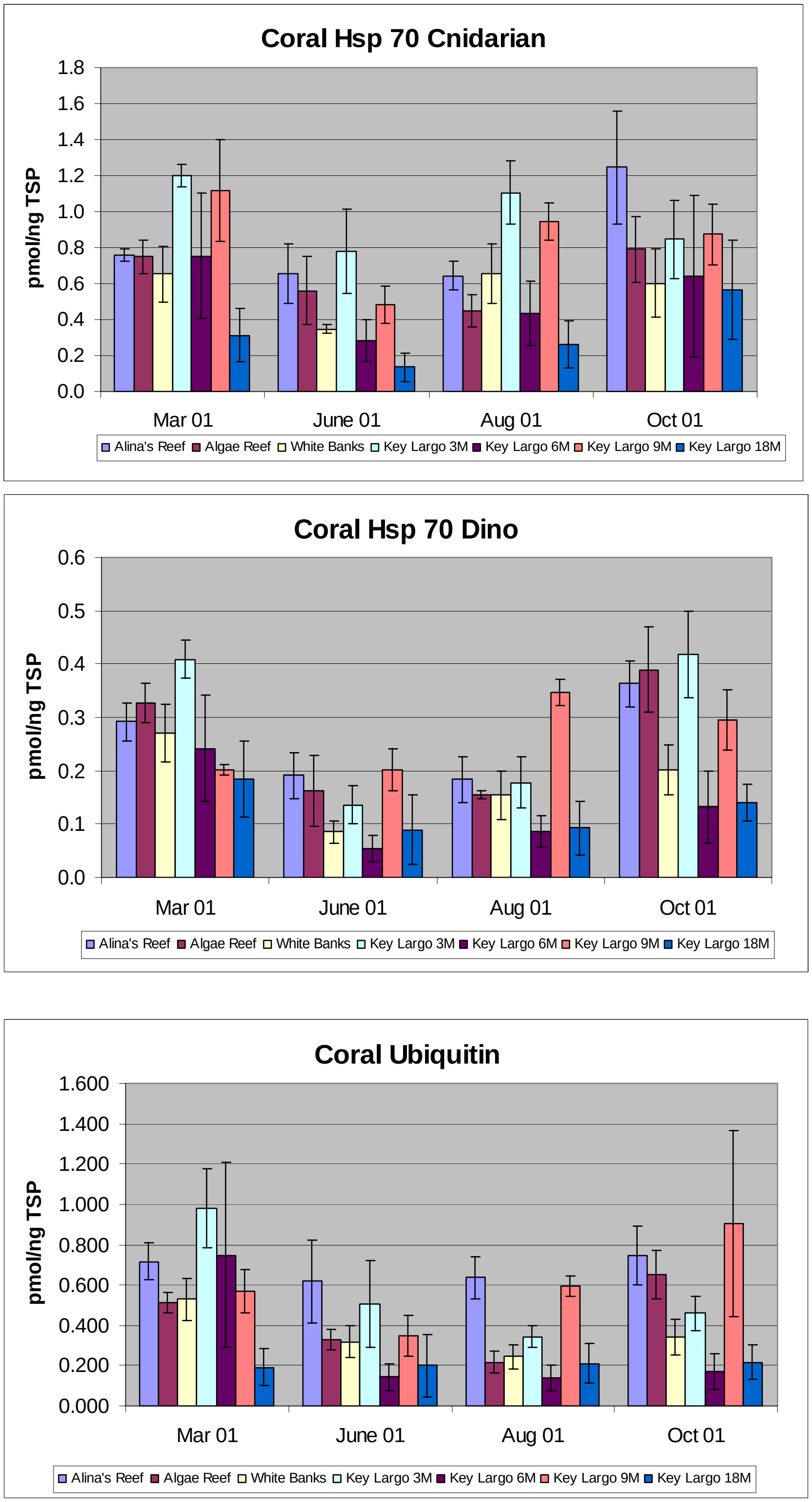
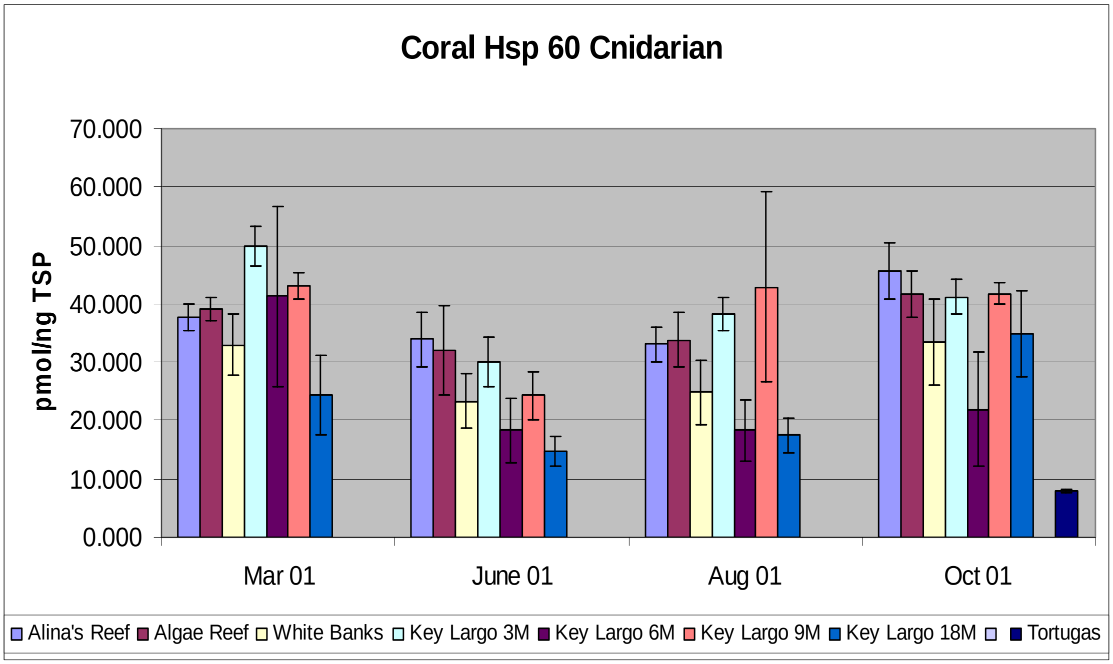


Figure 7. Protein metabolic condition of corals 2001.



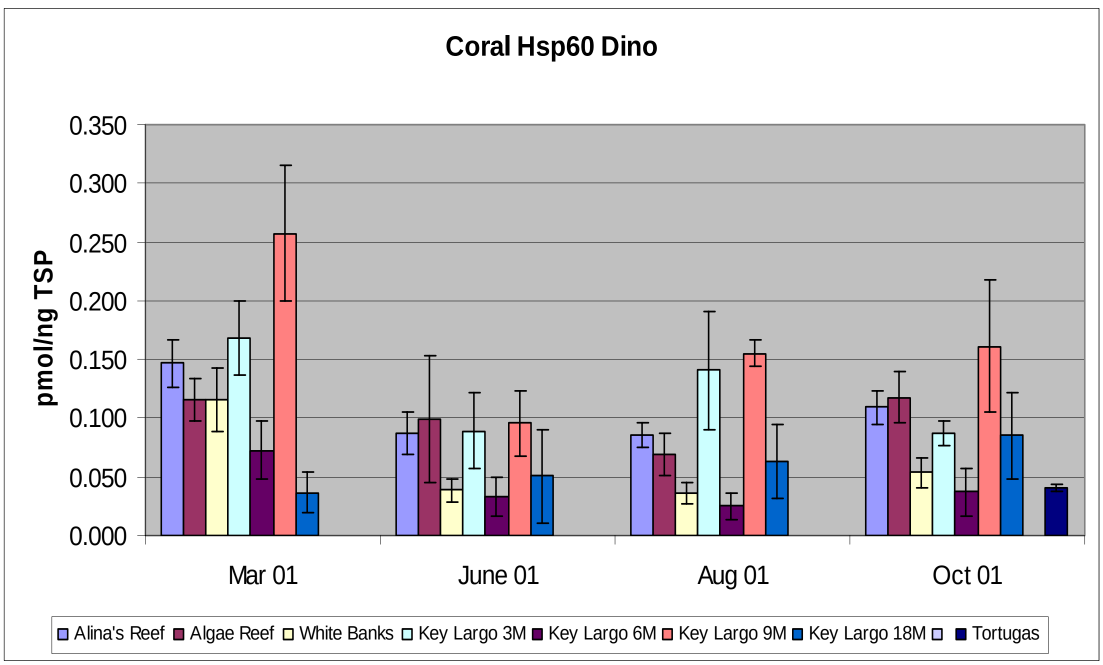


Figure 7. Protein metabolic condition of corals 2001 (cont’d).

Oxidative Stress

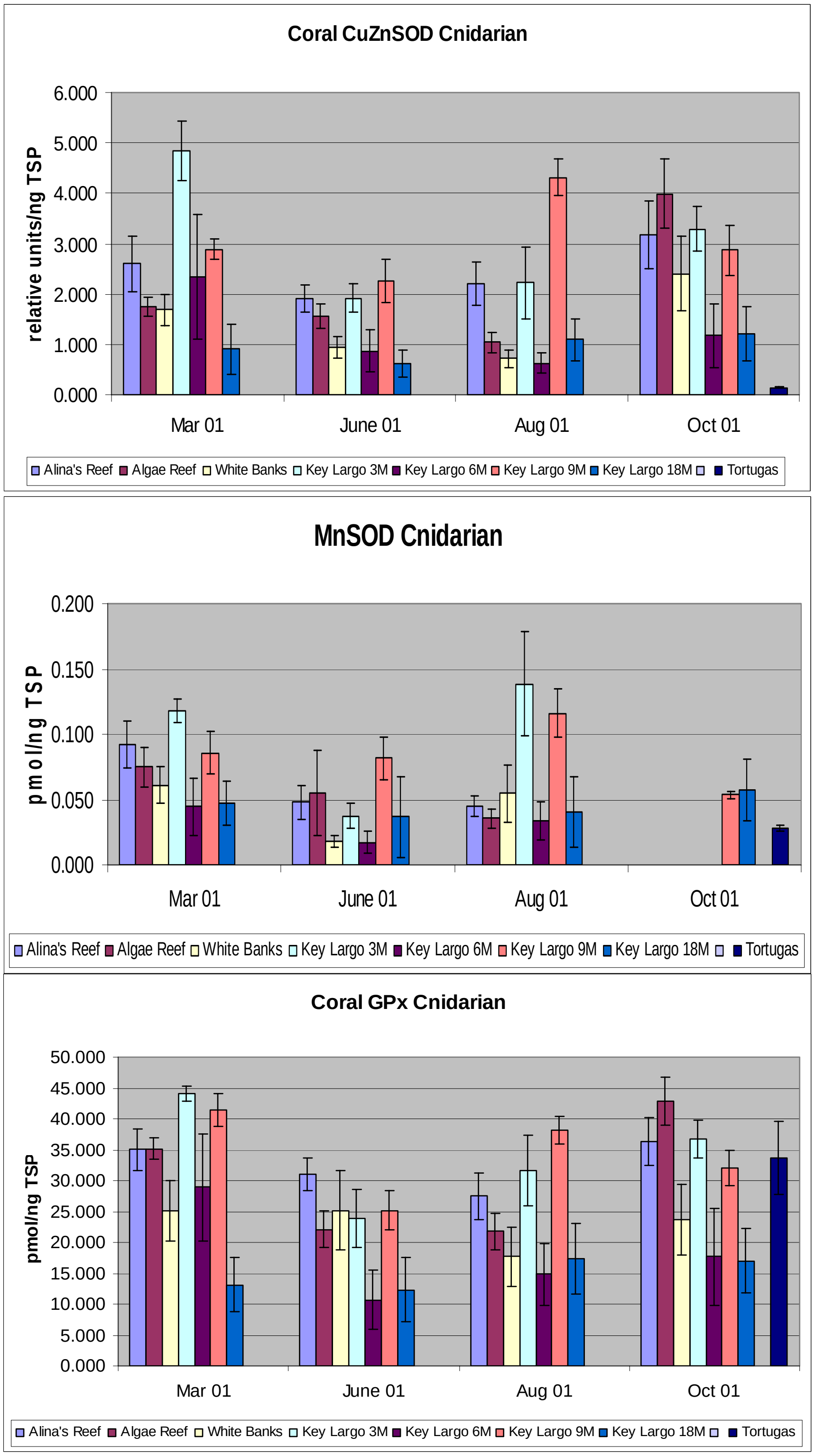


Figure 8. Oxidative stress condition of corals 2001.

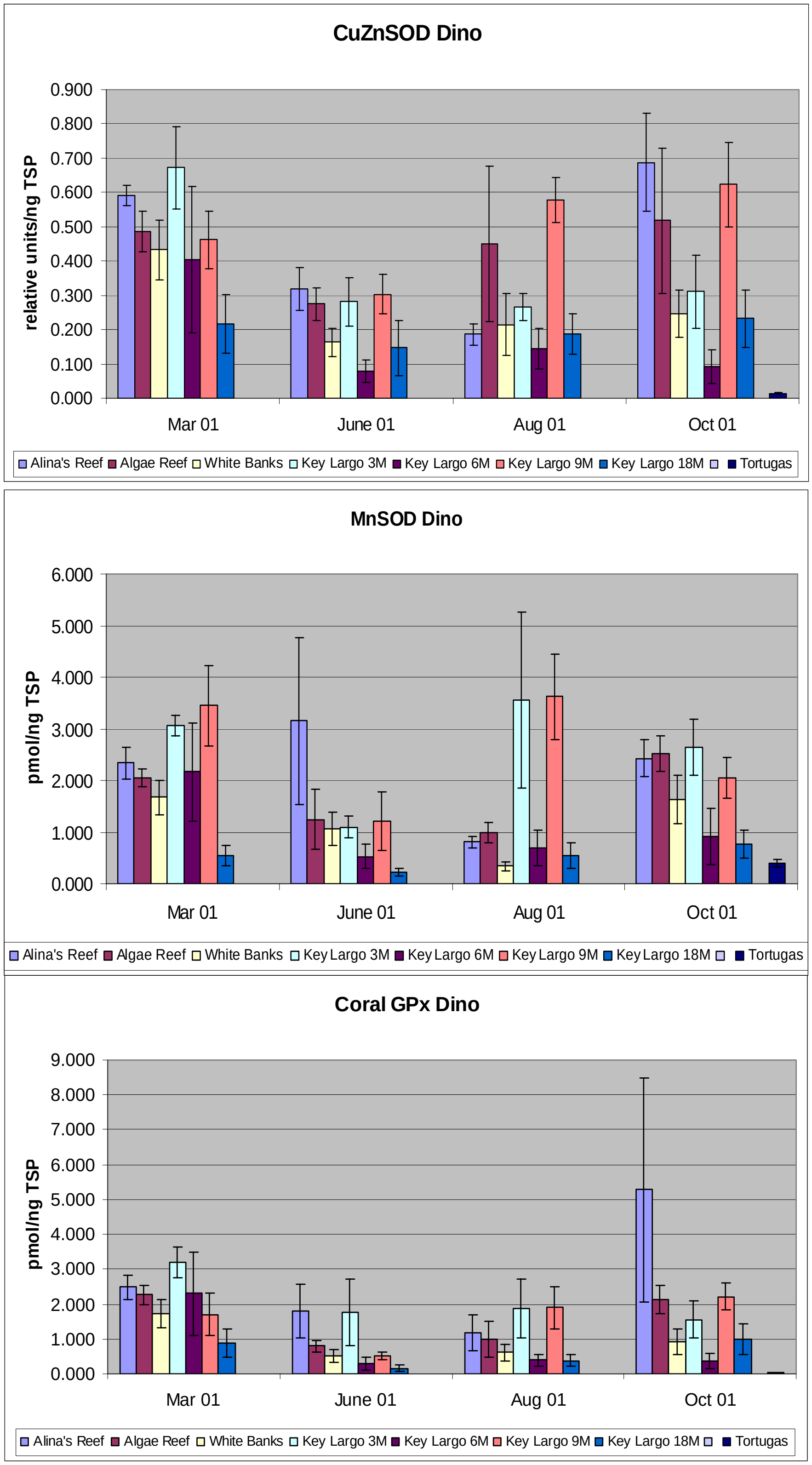
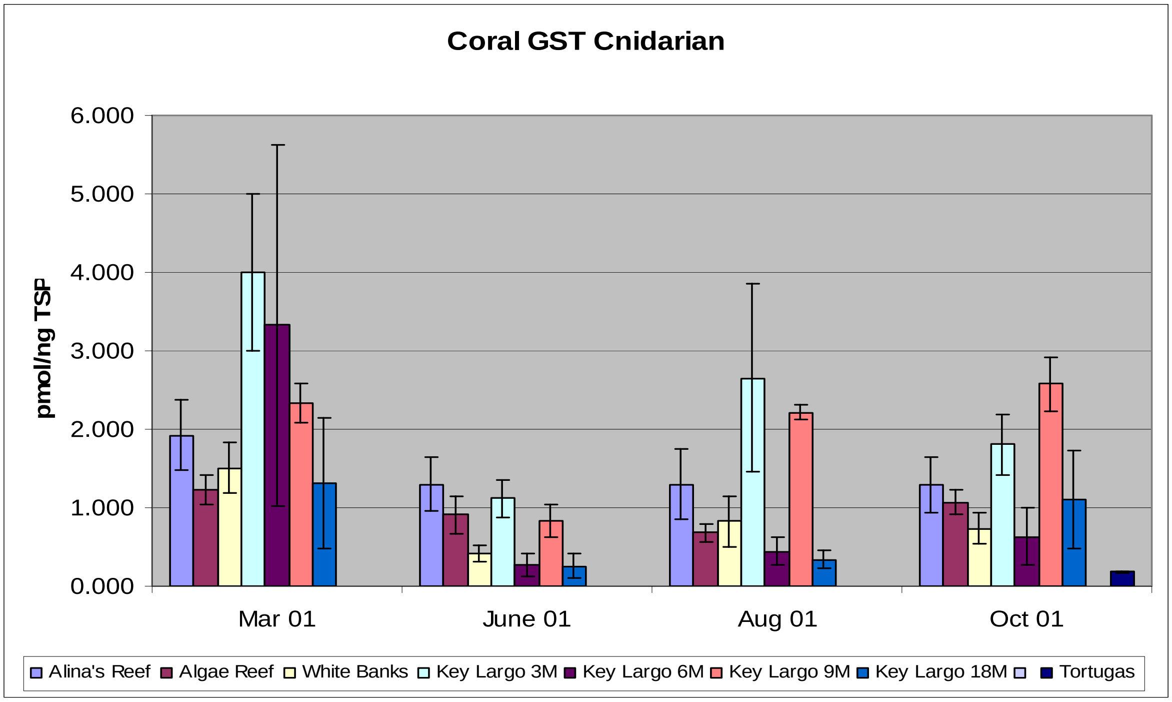


Figure 8. Oxidative stress condition of corals 2001 (cont'd).

Xenobiotic Detoxification



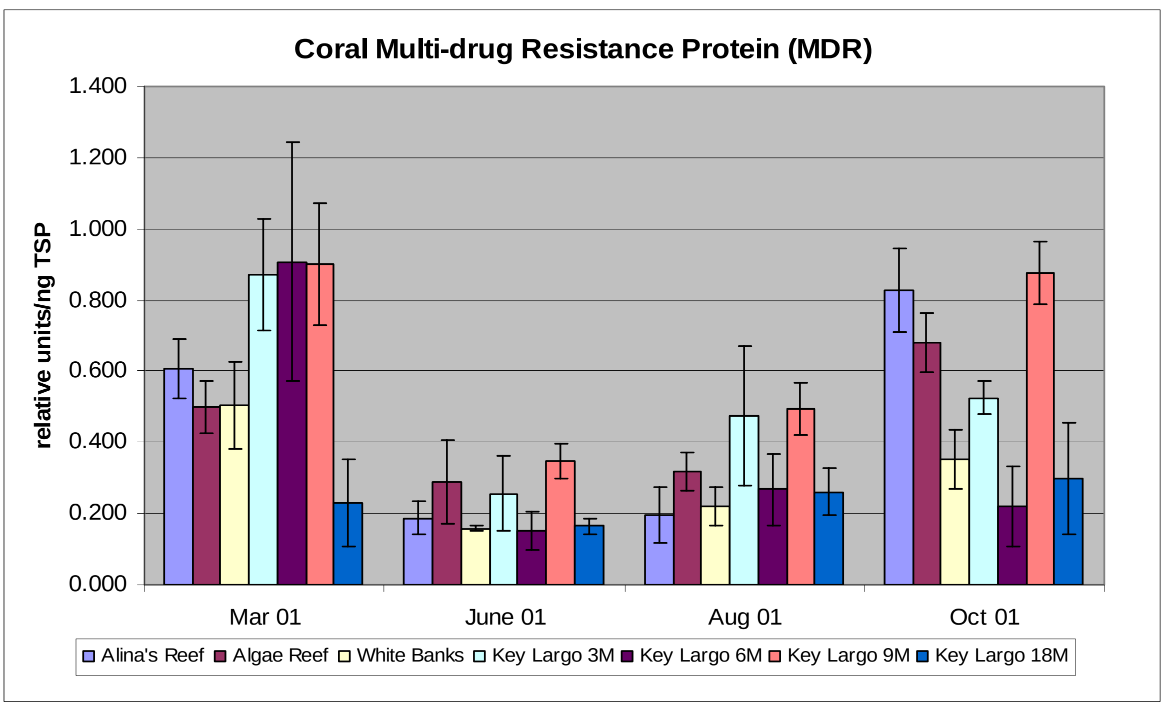
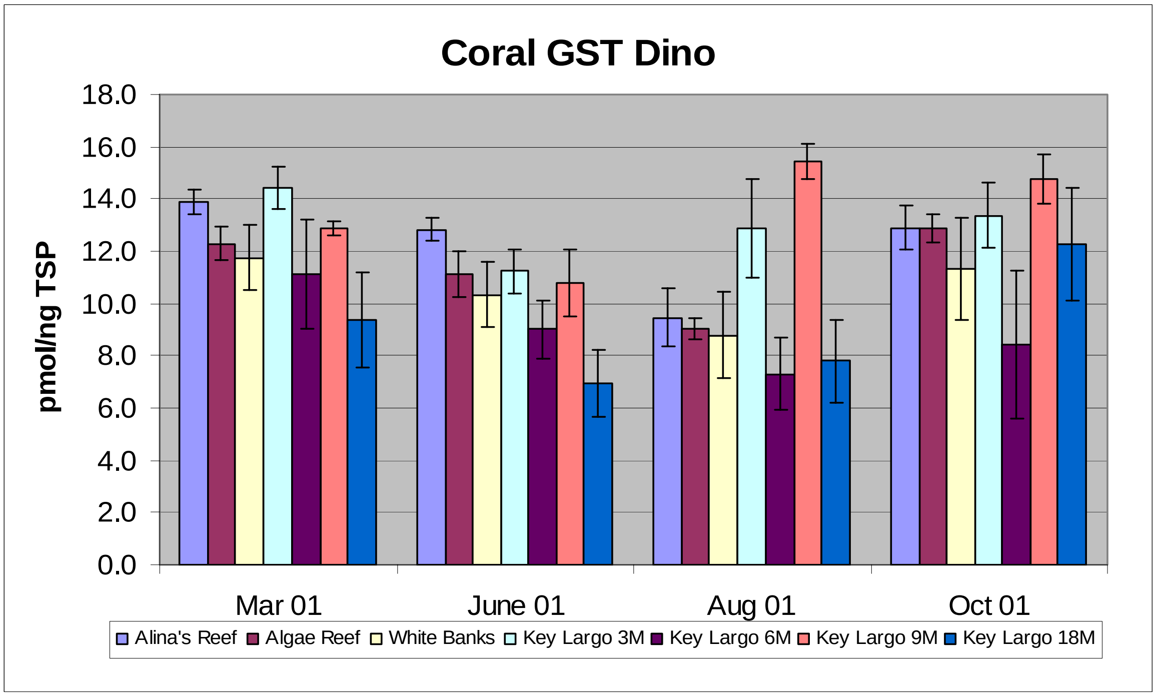


Figure 9. Xenobiotic detoxification response in corals 2001.



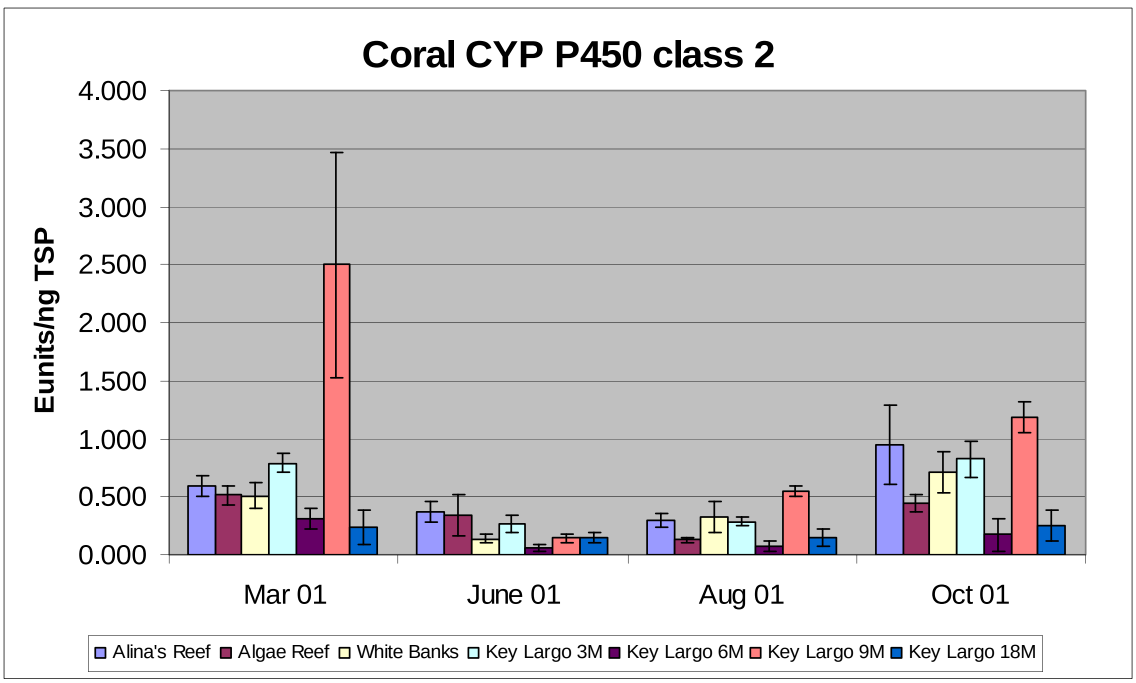
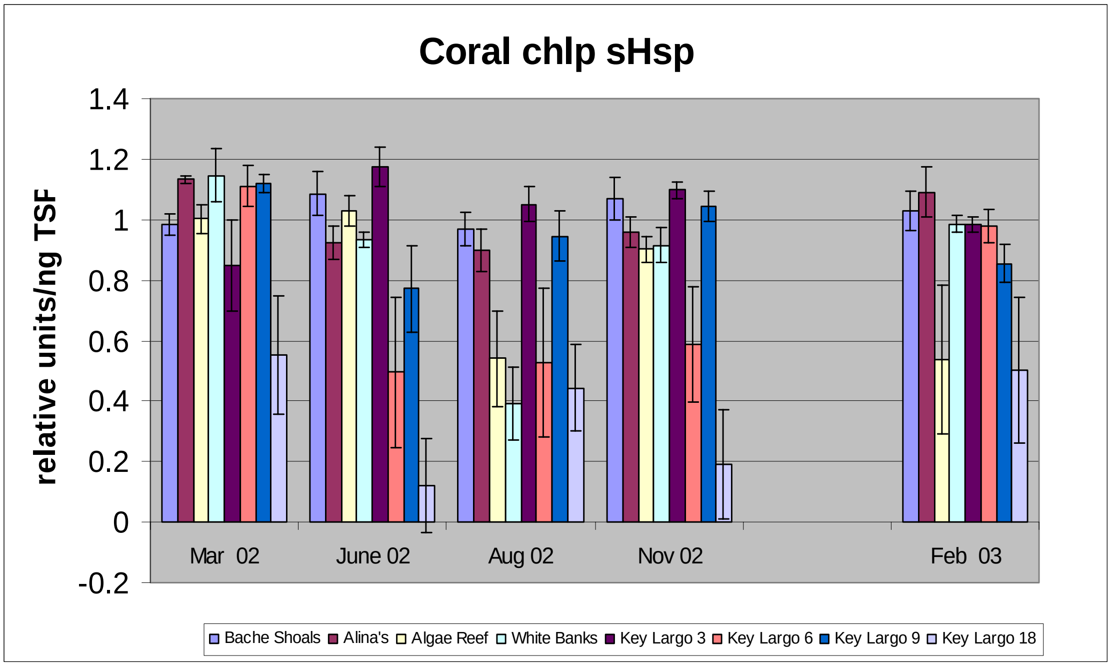


Figure 9. Xenobiotic detoxification response in corals 2001 (cont'd).

Metabolic Condition



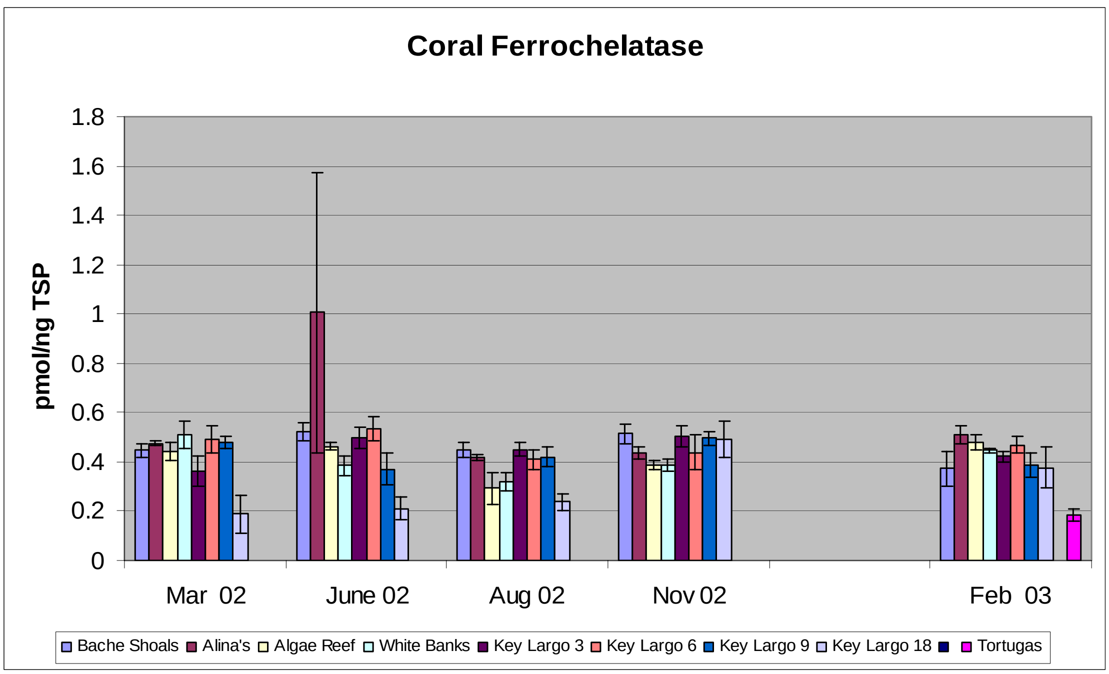
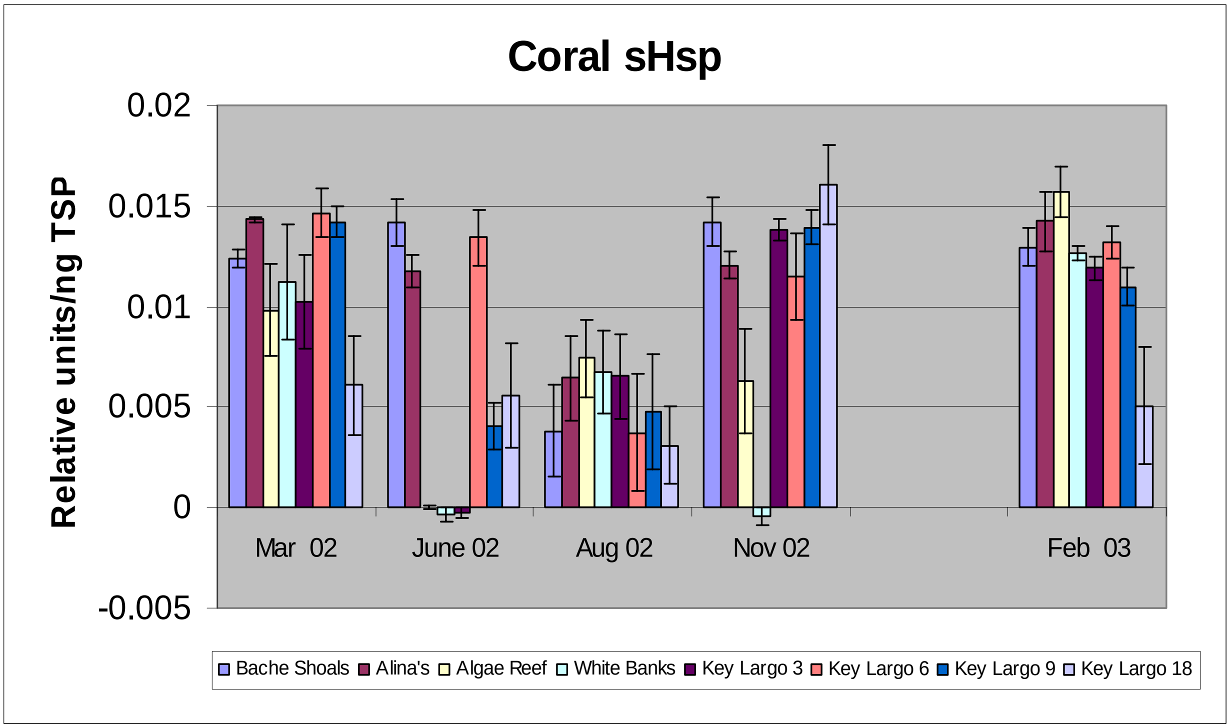


Figure 10. Metabolic condition of corals 2002-03.



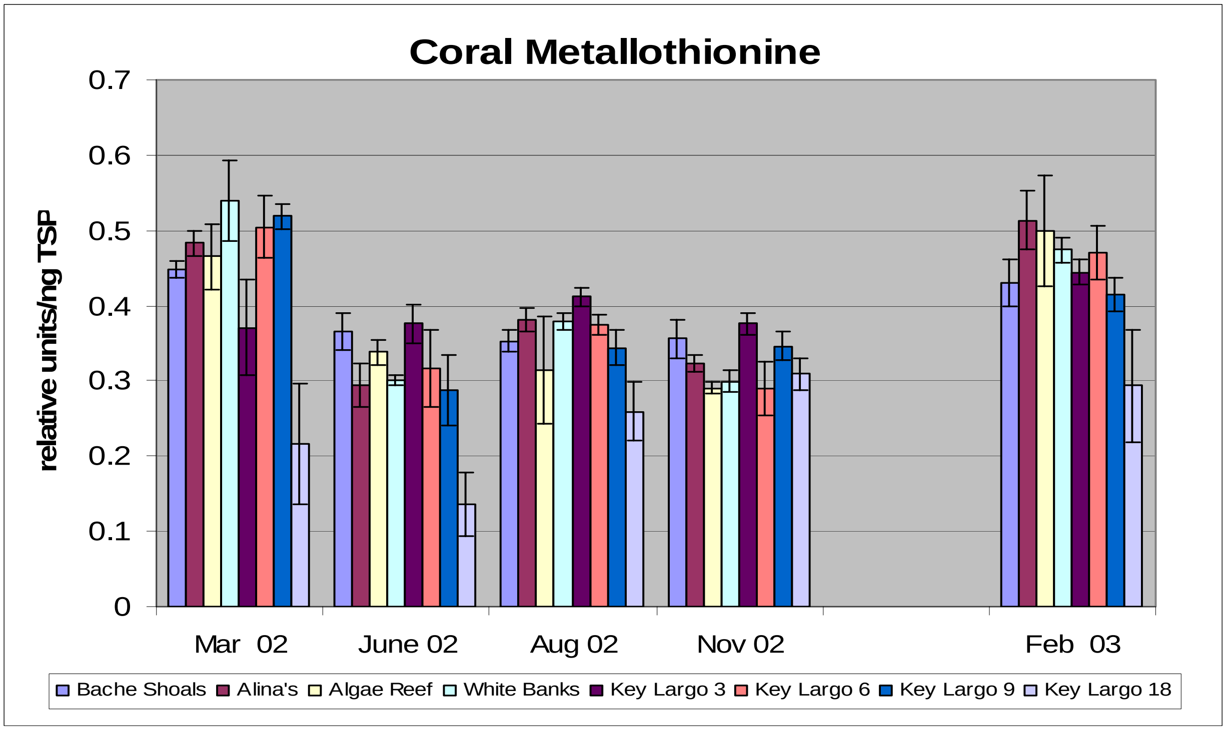


Figure 10. Metabolic condition of corals 2002-03 (cont'd).

Oxidative Stress

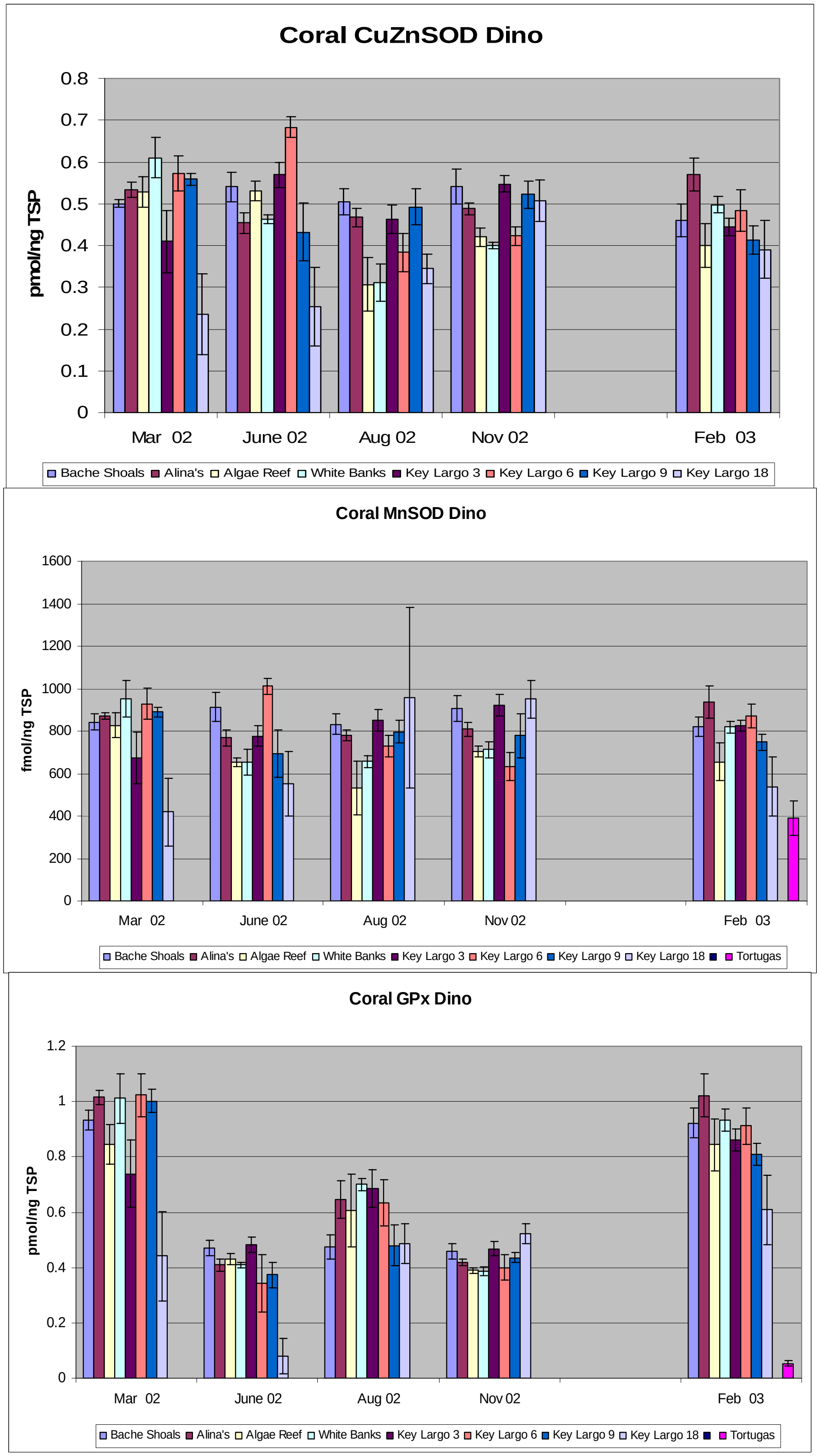


Figure 11. Oxidative stress in corals 2002-03.

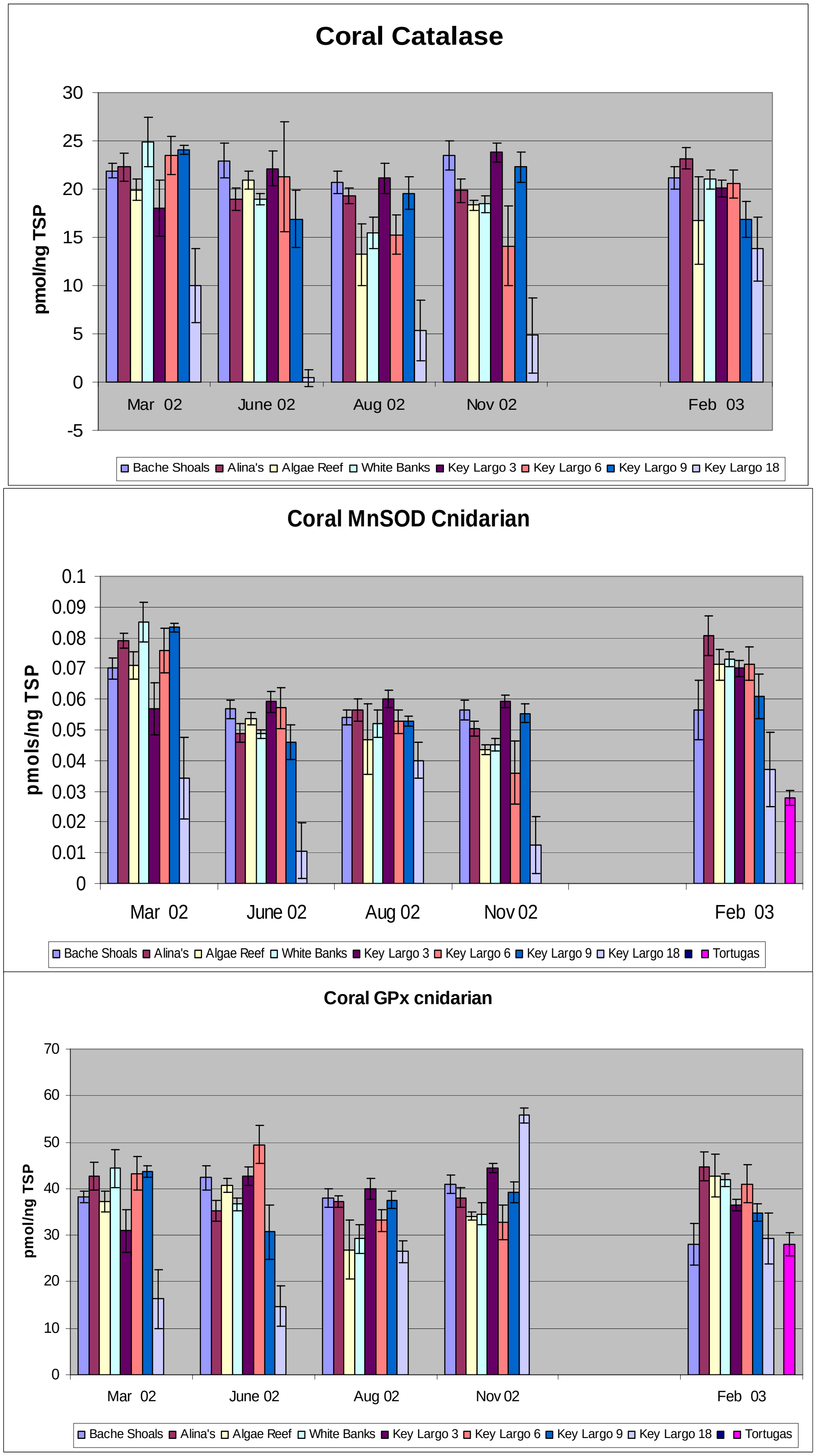
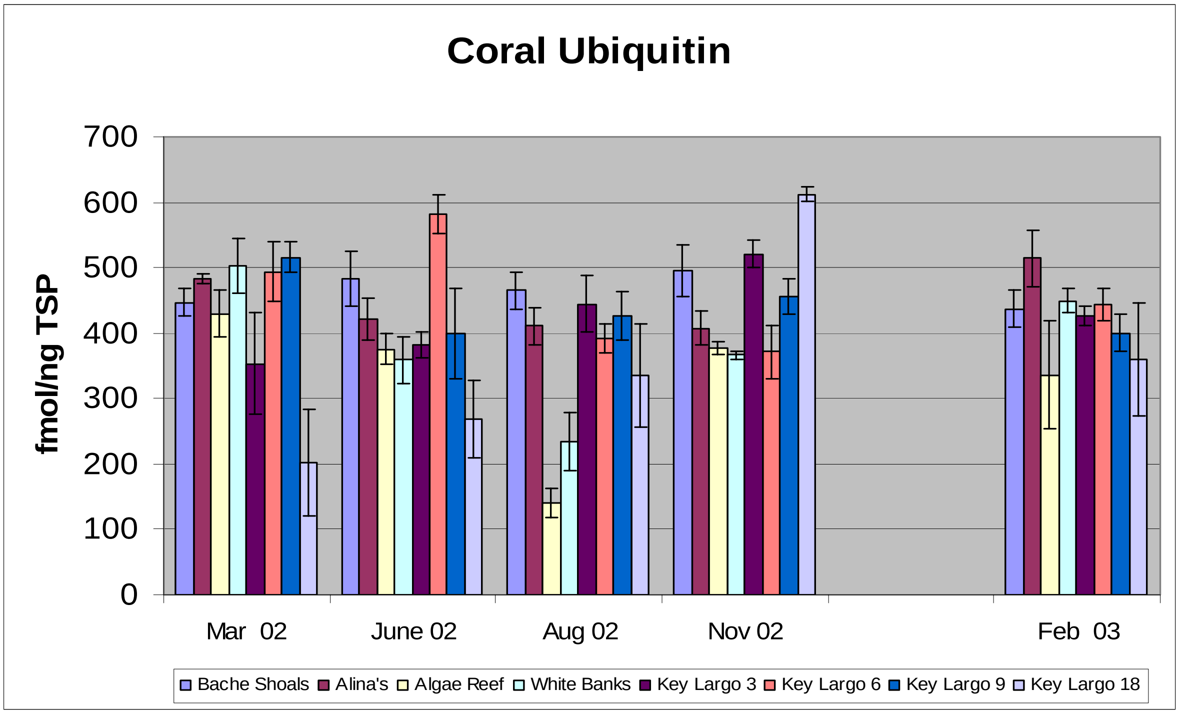


Figure 11. Oxidative stress in corals 2002-03 (cont'd).

Protein Metabolic Condition



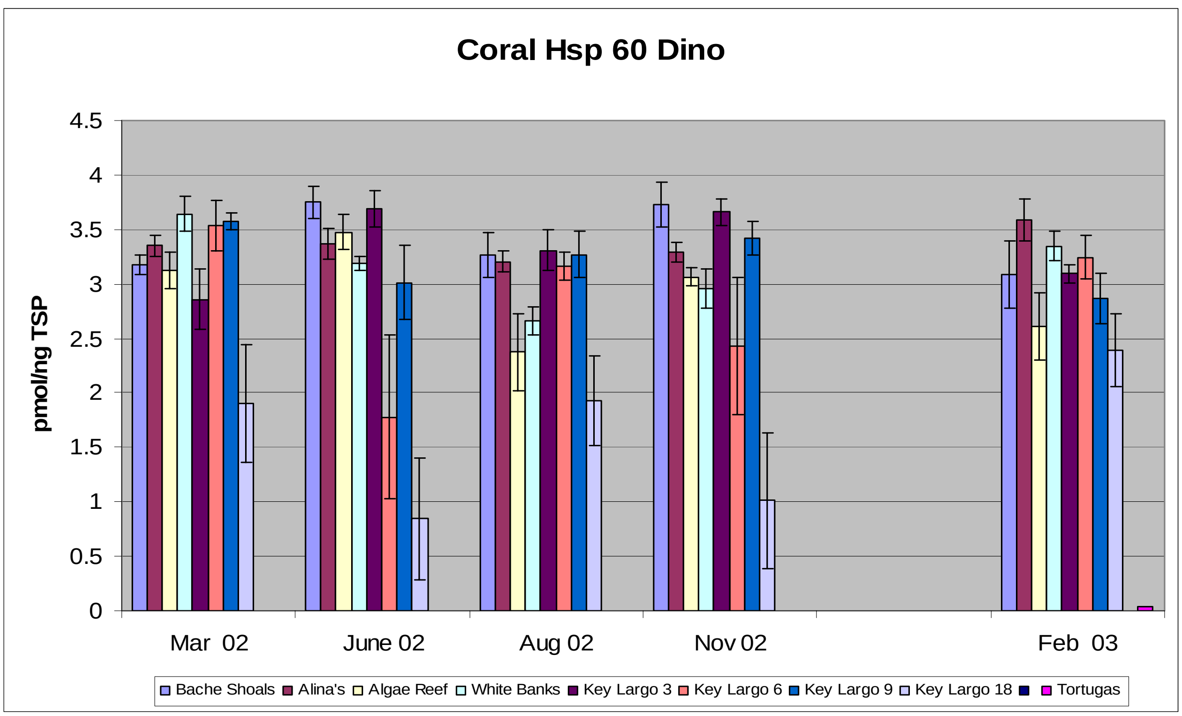
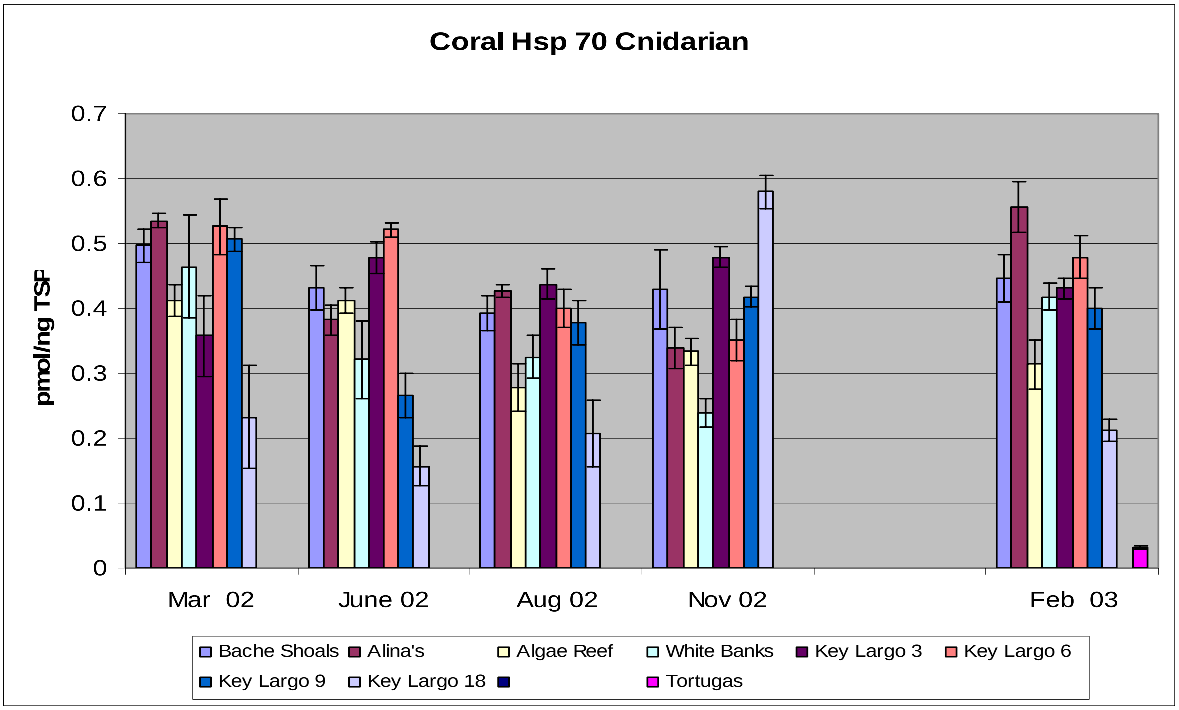


Figure 12. Protein metabolic condition of corals 2002-03.



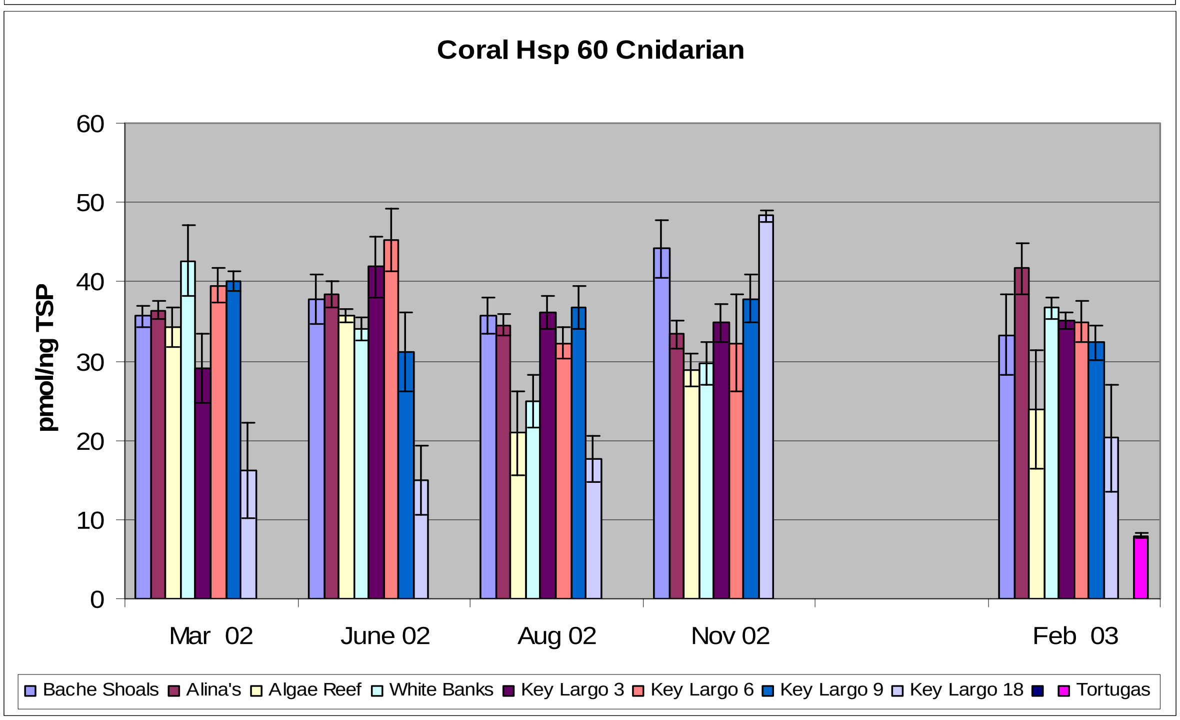


Figure 12. Protein metabolic condition of corals 2002-03 (cont'd).

Xenobiotic Detoxification

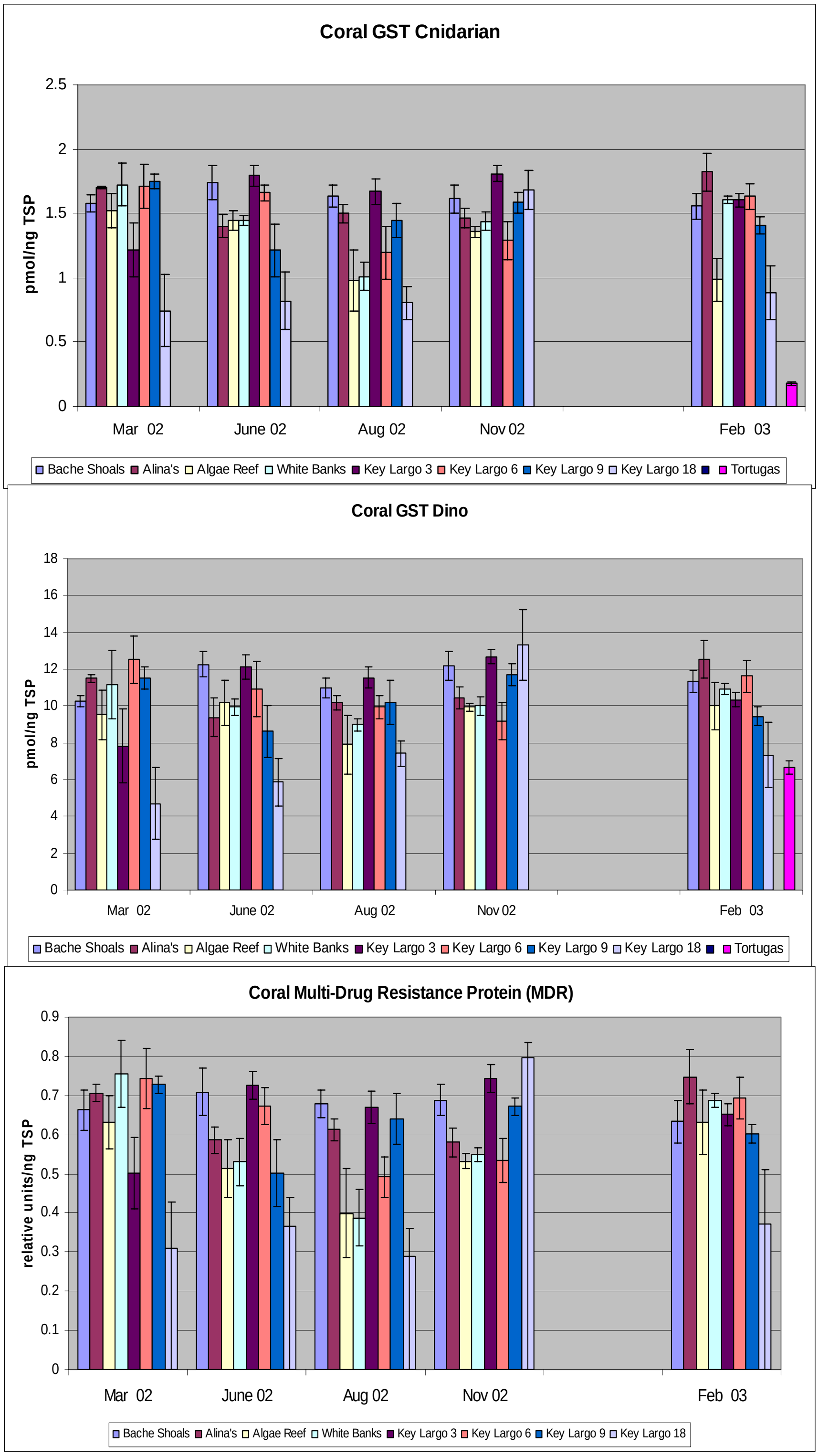
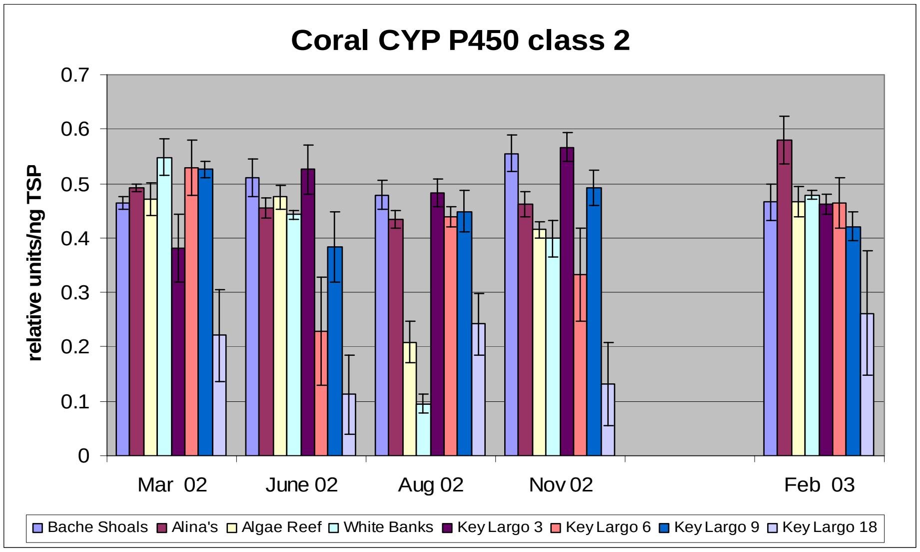
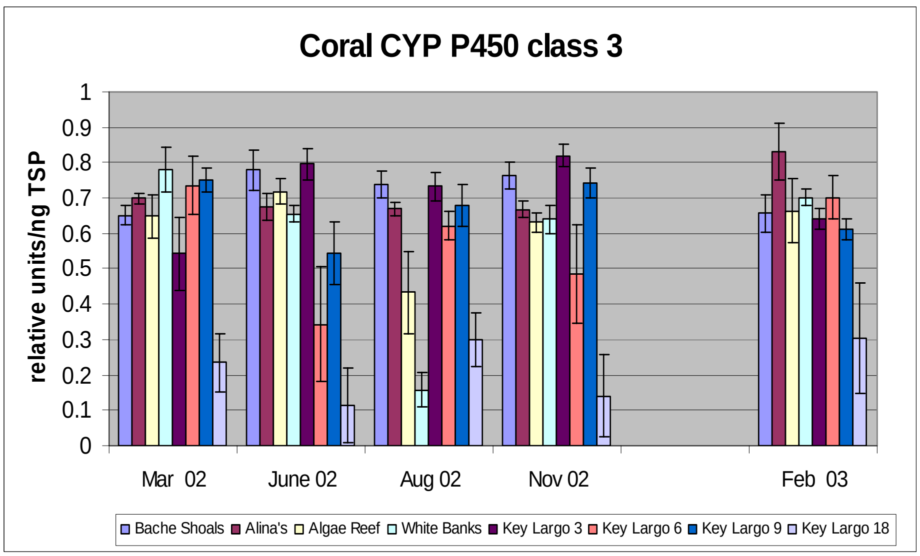


Figure 13. Xenobiotic detoxification in corals 2002-03.





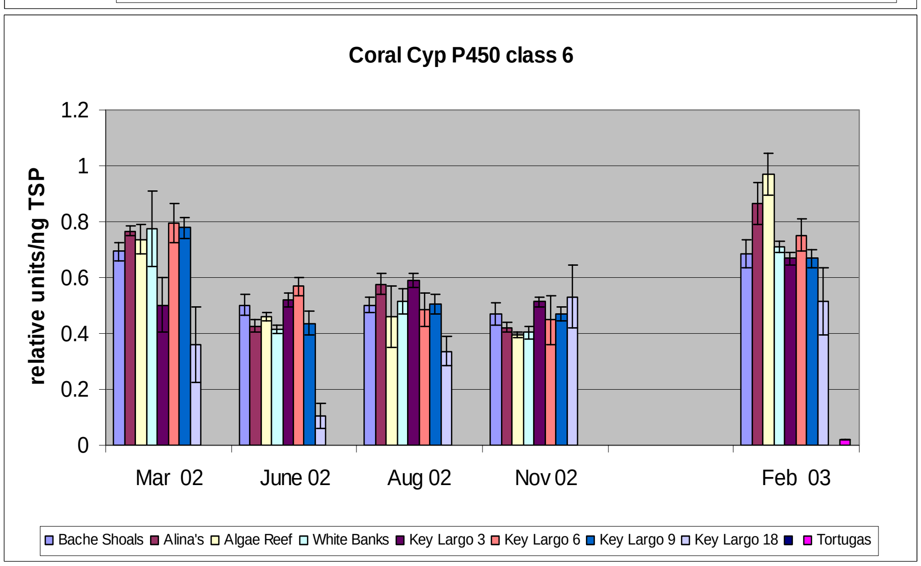


Figure 13. Xenobiotic detoxification in corals 2002-03 (cont'd).

We tested the condition of four subcellular systems that represented metabolic condition, protein metabolic condition, oxidative stress, and xenobiotic exposure. The profiles that were generated provided evidence in support of the efficacy of using CDS in coral health assessment protocols. Our findings provided evidence that corals were responding to different stressors at different locations at different times and further that these were not individual stressors, but rather multiple stressors were responsible for physiological responses being observed. In some locations this meant healthy corals able to cope with the stressors and in other locations, coral death (loss of all living tissue). In general, the coral *Montastraea annularis* at Algae Reef, White Banks Dry Rocks, and the Key Largo 3-m sites appeared to be physiologically stable, but did show increased stress compared to coral located in the Dry Tortugas. In contrast, corals at the two reefs in BNP (Alina's Reef and East Bache Shoals) and at the 6-, 9-, and 18-m sites (sites 2-4) in the FKNMS showed elevated levels of stress and overall poor physiological health. By February 2003, colonies at the 9-m site showed heavy algal overgrowth and two colonies with very little live tissue remaining. At the 18-m site colonies appeared to be dying and one colony had lost all living tissue. The trend over two years of sampling was a general decline at the 9- and 18-m sites (sites 3 & 4) with at least one colony completely dying.

In general, responses varied throughout the year with the winter months (late October through March) appearing more stressful, and with summers less stressful. This is in contrast to 1999, which was a year with unusually high sea surface temperatures. The profiles obtained from 2000 through February 2003, we believe, are reflective of local conditions, and the physiological profiles of each of these trophic levels provide evidence of multiple anthropogenic stressors impacting coral ecosystem health. In developing a pilot prognosis based on these profiles we predict that colonies that are stress-compromised will decline (Key Largo 6- and 18-m), and that colonies at Alina's Reef are declining faster than expected and are subjected to different stressors than other sites. The profiles indicate that colonies at White Banks Dry Rocks are near their tolerance threshold and may experience a rapid change in status and that colonies at Algae Reef and the Key Largo 3-m site should remain healthy.

Objective 4

The condition of corals at selected sites in Biscayne National Park (BNP) and in the upper Florida Keys National Marine Sanctuary (FKNMS) has been assessed at multiple scales in order to compare the precision, sensitivity, and prognostic capabilities of the CDS with measures traditionally used to assess ecosystem health. Community-scale condition of selected patch reefs was assessed using the well established Atlantic and Gulf Rapid Reef Assessment (AGRRA; Ginsburg et al. 2000). This protocol determines the condition of reefs by evaluating major benthic taxa that comprise them: coral and algae. The condition (i.e., mottling or bleaching) of populations of a key symbiont-bearing foraminiferan (*Amphistegina gibbosa*), living in the vicinity of the corals, is also being monitored according to Hallock et al. (1995). These data will be used to determine if there is a correlation between bleaching stress in the foraminiferan and bleaching or other stress responses in corals. This information will help determine if foraminifera can be used as a surrogate for studies of the mechanisms of coral bleaching. Individual-scale studies include monitoring lesions on corals (Meesters et al. 1997) and the assessment of overall condition (i.e., bleaching, disease, overgrowth, etc.) of the sampled corals. These assessments are compared to measures of health status taken at the cellular physiological level in a coral (*Montastraea annularis*), two fishes (*Haemulon plumieri* and *Stegastes partitus*), an alga

(*Halimeda opuntia*), and a snail (*Coralliophila abbreviata*) using a Cellular Diagnostic System (CDS) (Downs et al. 2000, 2001). The Cellular Diagnostic System assesses indicators of cell integrity indicative of stressed or non-stressed conditions. Environmental data are also being collected, including continuous water temperature measurements (using HOBO data loggers) and nutrient levels (taken at the time of biological sampling), sediment-trap data, and data from other ongoing monitoring studies. The environmental data will be analyzed in conjunction with community, population, coral condition, and molecular data to develop a more comprehensive overview of coral ecosystem health and provide evidence for the underlying stresses.

Lesion Regeneration

To date, we have compared coral lesion healing with levels of cellular parameters at one site in Biscayne National Park (Alina's Reef) and five sites in the upper Florida Keys National Marine Sanctuary that represent both a depth gradient (3.1-18.3 m) and geographic distribution (3 sites each at 6.1 m depth). To accomplish this, we tagged corals (*Montastraea* complex) that were to be sampled. Corals were sampled using a 1.5-cm punch, removing an approximately 3-mm deep "divot" of tissue from the colony surface. The sampling employed a repeated measures design on a quarterly basis in 2001 and 2002 (March/April, June, August/September, and October/November). The lesions (defined as an area on the colony with no live coral tissue) were monitored by photographing each lesion using a Nikonos V camera with a close-up adapter at each of the quarterly sampling events. Photographs were scanned to digital images, and then the area and perimeter of the lesions were calculated using image analysis software. Tissue samples were analyzed by ELISA for 20 cellular parameters included in the CDS. Our hypothesis was that a coral, which the CDS indicates to be more stressed, would be less likely to regenerate than a coral that CDS indicates to be less stressed.

In March, lesions from the Key Largo 3-m site experienced a large degree of regeneration with some lesions closing completely (Fig. 14A and 15A). Other sites, such as the Key Largo 10-m site, experienced very little regeneration with some lesions showing increases in mortality (Fig. 14B and 15A). However, in June, lesions from the Key Largo 10-m site appeared to regenerate the best, relative to lesions from the shallower corals at the Key Largo 6- and 3-m sites (Fig. 15B). Algae Reef (site 6) and White Banks (site 5) showed the greatest amount of regeneration year round relative to the other two 6-m sites, Alina's Reef and the Key Largo 6-m site, which show very little change year round (Fig. 8A and 8B).

Results of a backward stepwise regression, to determine which of the cellular parameters explained significant variation in coral re-growth, indicated that re-growth was correlated with depth and five of the cellular parameters: MDR (multi-drug resistance protein), dinoflagellate heat shock protein (Hsp) 60, cnidarian Cu/Zn superoxide dismutase, dinoflagellate Mn superoxide dismutase, and dinoflagellate glutathione peroxidase. Corals with high levels of plant Hsp 60 and plant glutathione peroxidase healed more quickly, indicating a healthy status. Lesions in corals with high MDR, cnidarian Cu/Zn superoxide dismutase, and plant Mn superoxide dismutase levels healed more slowly, suggesting they were stressed with a xenobiotic, thus allocating less of their energy to regeneration. These analyses indicate that corals located at Algae Reef showed significantly higher re-growth of lesions than those at the 9- and 18-m sites off of Key Largo.

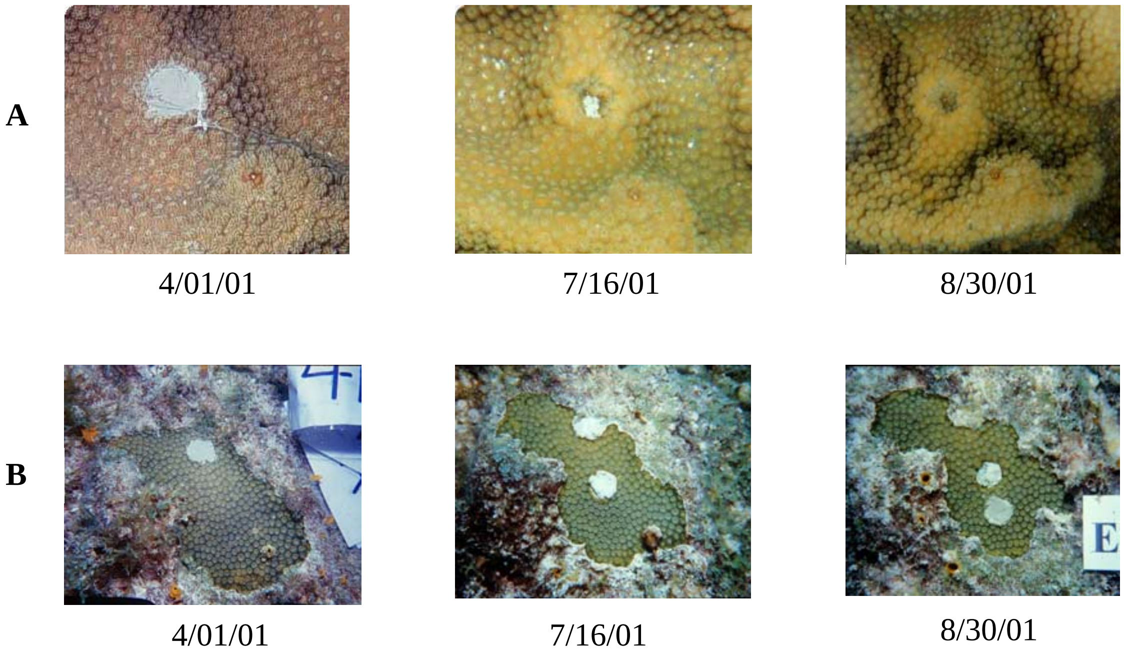


Figure 14. Change in lesion size between March and August 2001: (A) Decrease in lesion size indicating regeneration of lesion at the Key Largo 3-m site. (B) Increase in lesion size indicating increased mortality and algal overgrowth at the Key Largo 9-m site.

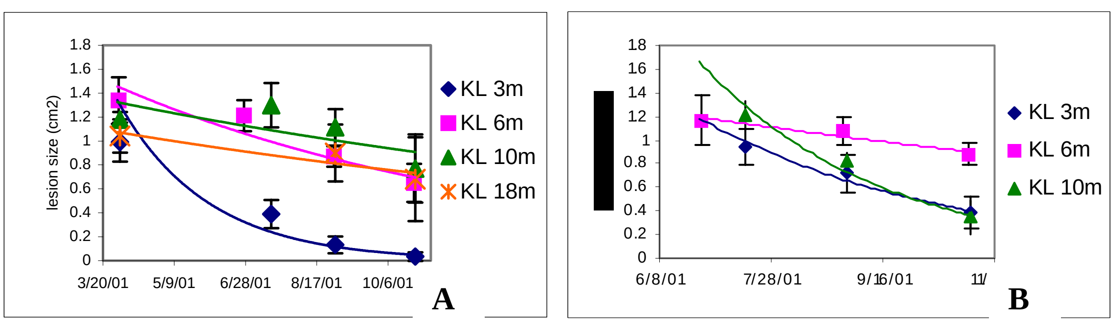


Figure 15. Change in mean lesion size (cm^2 ± SE) along a depth gradient of 3, 6, 10, and 18 m in Key Largo. Lines fitted to an exponential model. (A) March sampling lesion (B) June sampling lesion.

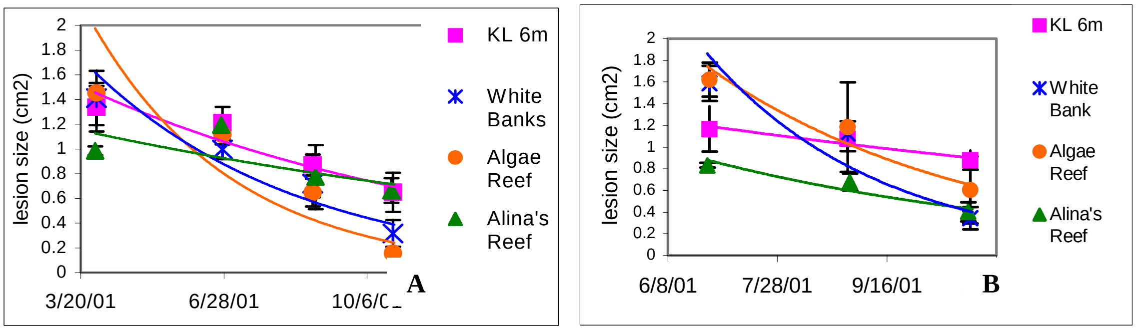


Figure 16. Change in mean lesion size (cm^2 ± SE) for the four 6-m sites including Key Largo 6-m (site 2), White Banks (site 5), Algae Reef (site 6), and Alina's Reef (site 7). Lines fitted to an exponential model. (A) March sampling lesion (B) June sampling lesion.

Sedimentation rates were highest at Algae Reef (site 6) and White Banks (site 5) throughout 2001-2002 (Fig. 17). Sedimentation rates were higher in 2001 than 2002 with the highest rates in the winter months (Fig. 17 and 18). Sedimentation data for the Key Largo 9- (site 3) and 18-m (site 4) sites was only collected in 2002 and during that year all sites along the Key Largo depth gradient had very low sedimentation rates (Fig. 18).

With the exception of June to August 2002, Algae Reef and White Banks had the highest regeneration rates of the 6-m sites between 2001 and 2002 (Fig. 3). Alina's Reef (site 7) and the Key Largo 6-m site (site 2) generally had low regeneration rates, but showed variability among colonies and seasons (Fig. 19). Regeneration rates were higher in 2001 than in 2002 for most sites, except for White Banks, which showed little change (Fig. 19). Seasonality was observed in regeneration with the winter months tending to have the lowest regeneration rates (Fig. 19). Sedimentation positively correlated with regeneration in 2001, and the 6-m sites, which had the highest sedimentation rates (Algae Reef, White Banks), also had the highest regeneration rates. Positive trends were still observed in 2002, but were no longer significant.

No depth trends were observed in regeneration in either 2001 or 2002. The Key Largo 3-m site (site 1) had relatively high regeneration rates throughout 2001-2002 with a significant increase in regeneration in 2002 (Fig. 20). The Key Largo 6-m site had relatively low regeneration rates throughout 2001-2002 (Fig. 20 and 21). High variability in regeneration among seasons and among colonies was observed at the Key Largo 9- and 18-m sites with some colonies showing high increases in mortality and other colonies showing the ability to regenerate lesions (Fig. 20 and 21).

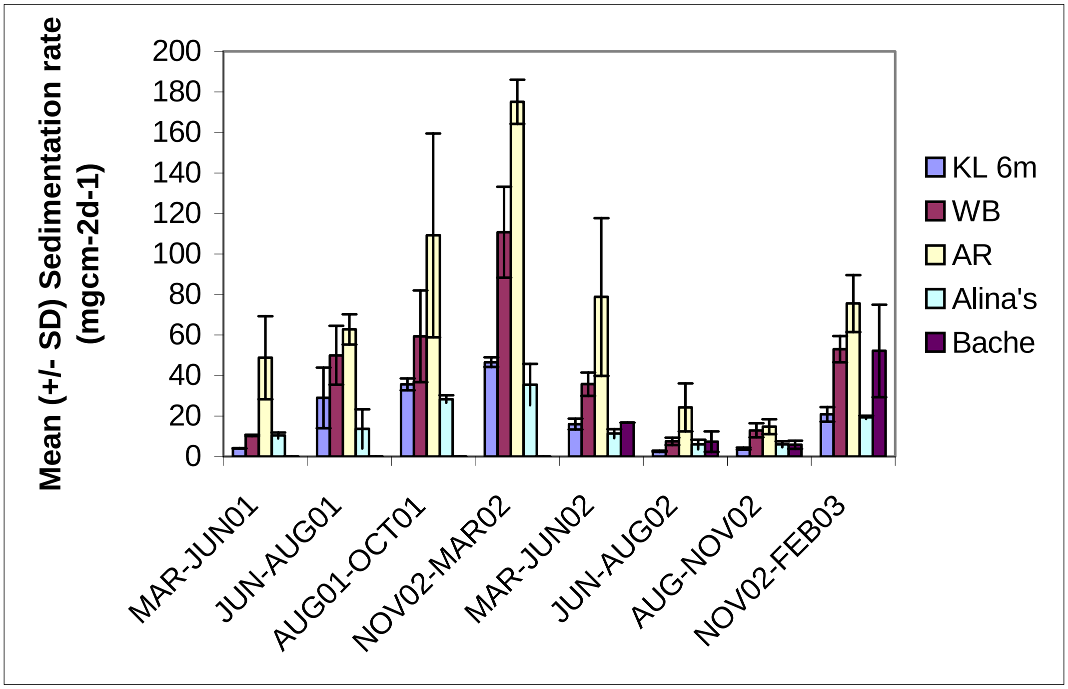


Figure 17. Mean sedimentation rates at 6-m sites, 2001-2003. Error bars represent standard deviations.

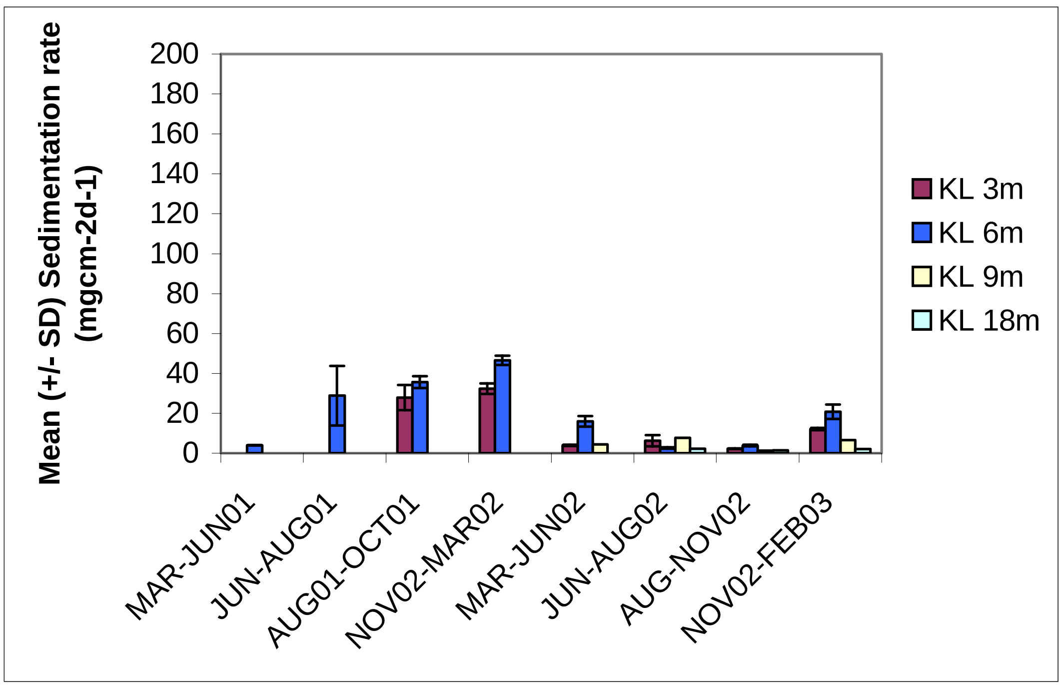


Figure 18. Mean sedimentation rates along Key Largo depth gradient, 2001-2003. Error bars represent standard deviations.

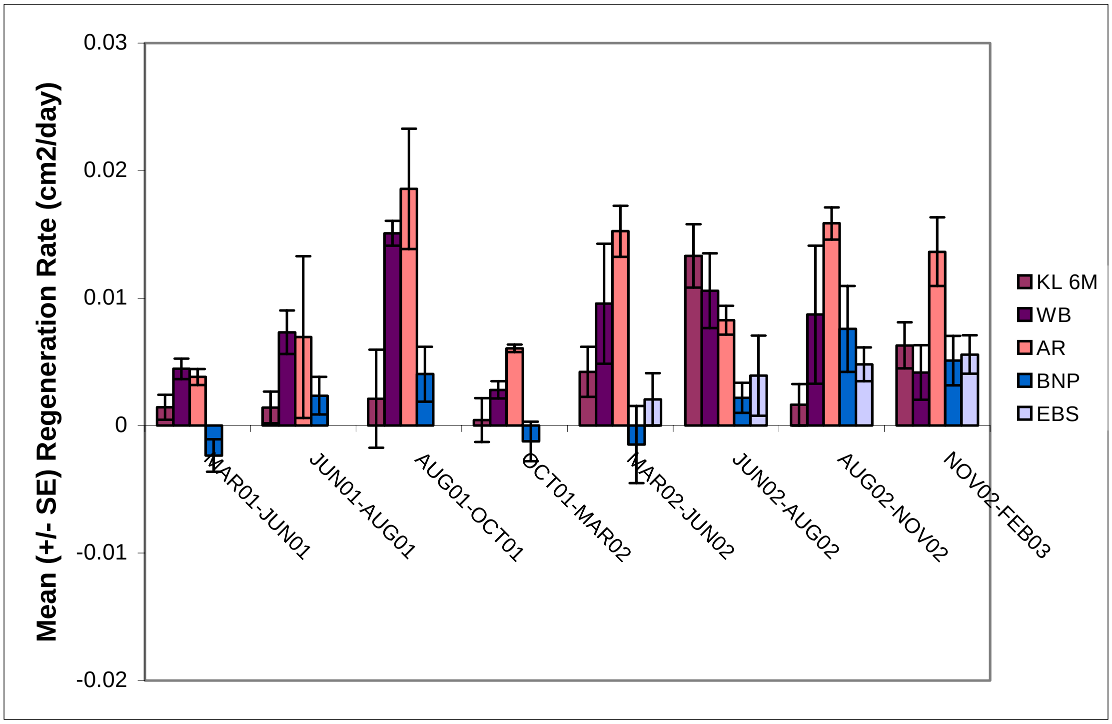


Figure 19. Mean regeneration rates at 6-m sites from 2001 to 2003. Error bars represent standard errors.

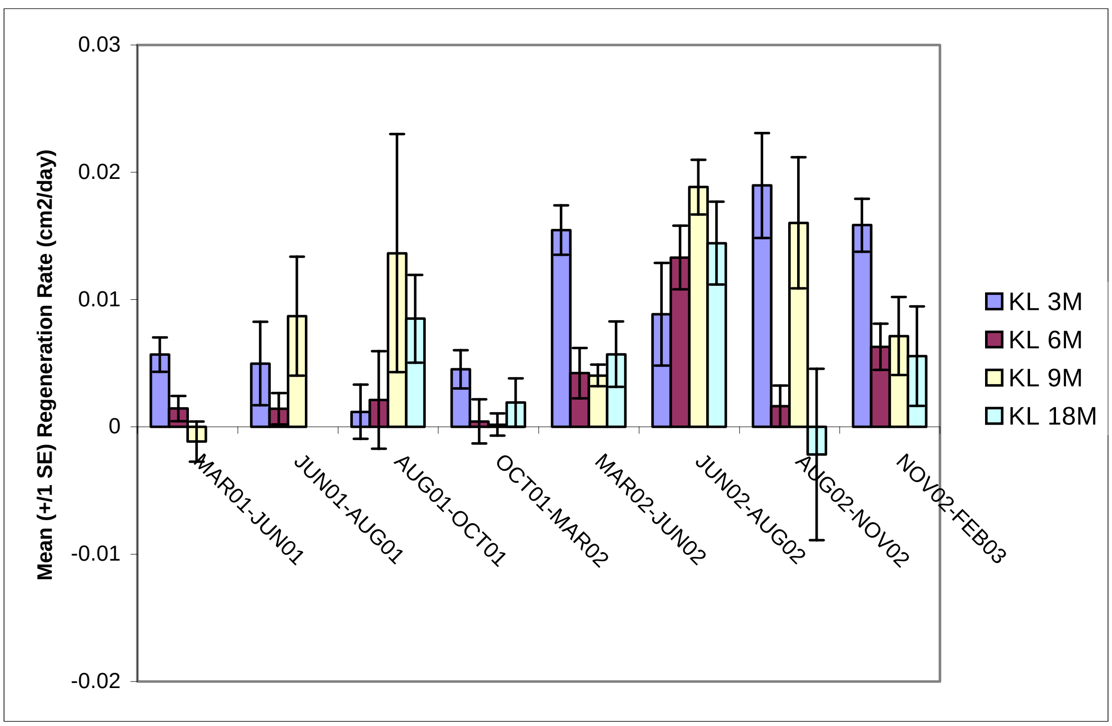


Figure 20. Mean regeneration rates along Key Largo depth gradient from 2001 to 2003. Error bars represent standard errors.

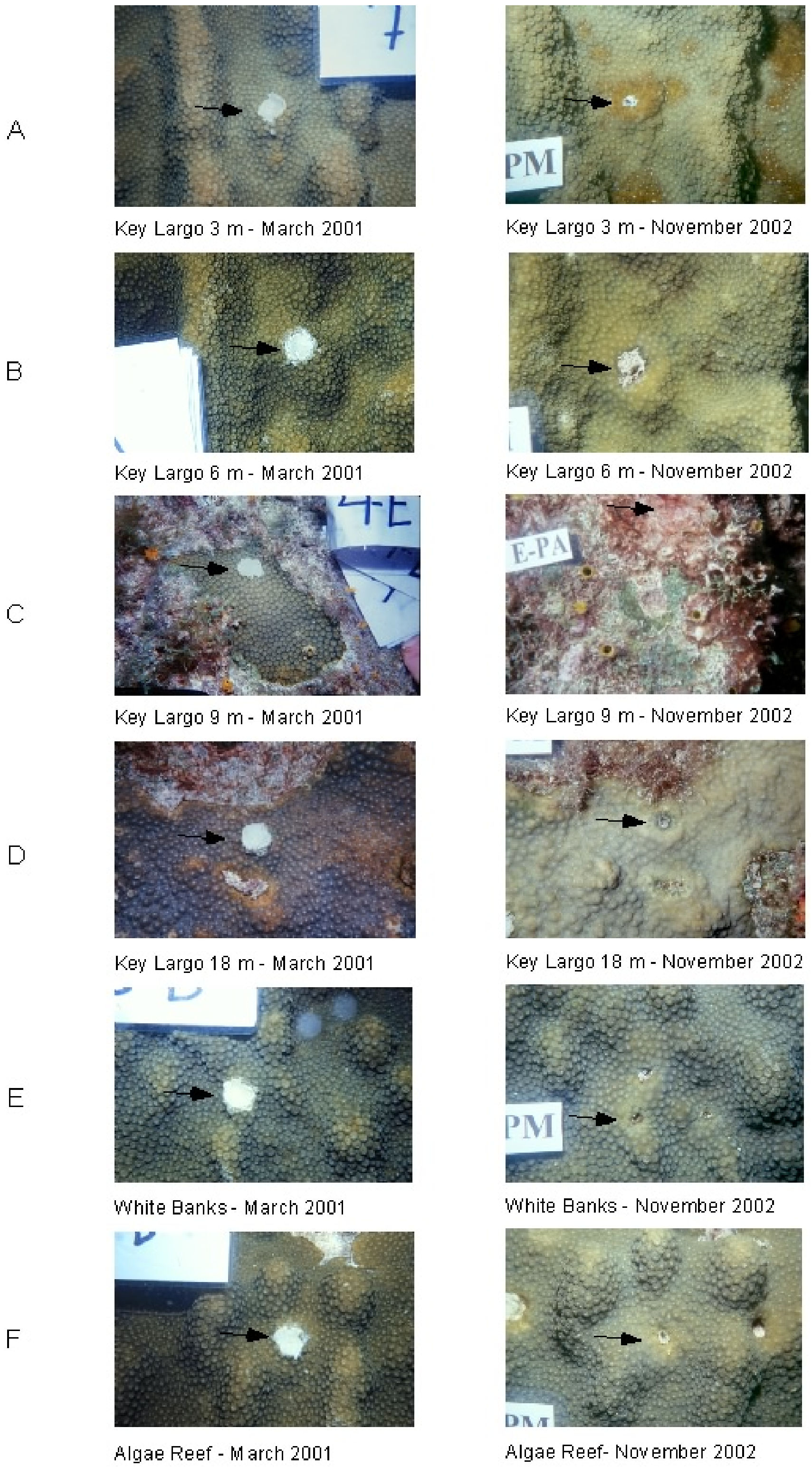


Figure 21. Sample pictures showing changes in lesion size between March 2001 and November 2002 at Sites 1-6: (A, D-F) Decrease in lesion size indicating regeneration of sampling lesion; (B) Little change in lesion size; (C) Complete loss of live tissue and algal and sponge overgrowth.

Objective 5

Throughout this project, we have welcomed the participation of individuals from many walks of life. We have had divers participate on various missions including: individuals from a local high school marine biology class, retirees from the local community, resource managers, graduate student volunteers, and industry. Through these interactions, we have been able to communicate with and educate others about the novel technology we are testing, the similarity of this technology to modern biomedicine, and the prospects that this technology brings to understanding coral reef degradation and development of science-based strategies to combat them. We have also engaged the scientific and resource management community in evaluating and critiquing our data and experimental design through a recent workshop (March 15, 2002). We had representatives from academia, the State of Florida, Biscayne National Park, USGS, Florida Keys National Marine Sanctuary, National Undersea Research Program, industry, Mote Marine Laboratory, and the National Ocean Service. They were able to review our data and provide critical input to our second-year design. Two significant recommendations from the meeting were to increase the spatial scale of the project and conduct laboratory challenge experiments with suspect stressors.

In January 2004, we held our final constitutive workshop for this project. Over 40 representatives from academia, non-profit organizations, and industry as well as local, state, and federal agencies attended. Our findings were well received and valuable constructive criticism was given by the participants. In summary the participants agreed that the technology was valuable and did show promise for providing useful information for conducting coral reef health assessment and had the capability of helping elucidate the “drivers” in coral reef system condition and response. We were encouraged to continue development of the CDS technology, specifically focusing on developing sound linkages between a specific stressor and a unique profile of physiological response, and the fate of the organism or population to exposures analogous to a forensic investigation that links the “victim, the smoking gun, and the bullet.”

References

Byrant, D., L. Burke, J. McManus, and M. Spalding. 1998. Reefs at risk: a map-based indicator of threats to the world’s coral reefs. World Resources Institute.

Downs, C.A., J. S. Coleman, S.A. Heckathorn. 1999. The chloroplast 22 kDa heat-shock protein: a lumenal protein that associates with then oxygen evolving complex and protects photosystem II during heat stress. J. Plant Physiol. 155: 477-487.

Downs, C.A., J.E. Fauth, J.C. Halas, P. Dustan, J. Bemiss and C. M. Woodley. 2002. Oxidative stress and seasonal coral bleaching. Free Rad. Biol. Med. 33: 533-543.

Downs, C.A., R.T. Dillon, J.E. Fauth, and C.M. Woodley. 2001. A molecular biomarker system for assessing the health of gastropods (*Illyanassa obsoleta*) exposed to natural and anthropogenic stressors. J. Exp. Mar. Biol. Ecol. 259(2): 189-214.

Downs, C.A., E. Mueller, S. Phillips, J.E. Fauth, and C.M. Woodley. 2000. A molecular biomarker system assessing the health of coral (*Montastraea faveolata*) during heat stress. Mar. Biotechnol. 2: 533-544.

Downs, C.A., S. Ryan, and S.A. Heckathorn. 1999. The chloroplast small heat-shock protein: evidence for a general role in protecting photosystem II against oxidative stress and photoinhibition. J. Plant Physiol. 55: 488-496.

Ginsburg, R.N., P. Kramer, J.C. Lang, P. Sale, and R.S. Steneck. 2000. Atlantic and Gulf Rapid Reef Assessment (AGRRA) Methodology, Version 3.1. http://coral.aoml.noaa.gov/agra

Hallock, P., H.K. Talge, E.M. Cockey and R.G. Muller. 1995. A new disease in reef-dwelling foraminifera: implications for coastal sedimentation. Journal of Foraminiferal Research 25: 280-286.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching, and the future of the world's coral reefs. Marine and Freshwater Research 50: 839-66.

Jaap, W.C., J.W. Porter, J. Wheaton, K. Hackett, M. Lybolt, M. Callahan, C. Tsokos, G. Yanev, and P. Dustan. 2000. Coral reef monitoring project executive summary. EPA Science Advisory Panel. Key Colony Beach, December 5-6, 2000.

McEwen, B.S., and J.C. Wingfield. 2003. The concept of allostasis in biology and biomedicine. Horm. Behav. 43: 2-15.

Meesters, E.H., W. Pauchli, and R.P.M. Bak. 1997. Predicting regeneration of physical damage on a reef-building coral by regeneration capacity and lesion shape. Mar. Ecol. Prog. Ser. 146: 91-99.

Seeman, T.E., B.H. Singer, J.W. Rowe, R.I. Horwitz, and B.S. McEwen. 1997. Price of adaptation--allostatic load and its health consequences: MacArthur studies of successful aging. Arch. Intern. Med. 157: 2259-2268.

Wilkinson, C. 2000. Status of coral reefs of the world: 2000. Global Coral Reef Monitoring Network. Australian Institute of Marine Science, Townsville.

Woodley, C.M., C.A. Downs, J.E. Fauth, E. Mueller, J.C. Halas, J.A. Bemiss, Y. Ben-Haim, and E. Rosenburg. In press. A novel molecular biomarker system to assess the physiological status of corals. Proceedings of the 9th International Coral Reef Symposium, Bali Indonesia.

Scientific Evaluation of a Sediment Fill Technique for the Restoration of Motor Vessel Injuries in Seagrass Beds of the Florida Keys National Marine Sanctuary

W. Judson Kenworthy, Kamille Hammerstrom, and Mark S. Fonseca (NOAA/NOS/NCCOS Center for Coastal Fisheries and Habitat Research, Beaufort, NC)

Project Description

Cost-effective techniques to facilitate early intervention for the prevention of propeller scar erosion and to enhance seagrass growth are widely needed to restore damage to Florida Keys National Marine Sanctuary (FKNMS) resources. This project used experimental manipulation to assess the effectiveness of installing fill material encapsulated in biodegradable fabric tubes to restore propeller scars. The experiment was designed to test the efficacy of sediment tubes, alone and in conjunction with bird stakes and *Halodule wrightii* seagrass planting units and to re-grade injuries to enhance regrowth of seagrass from the margins of propeller scars.

Introduction

Deterioration in seagrass habitat has been attributed to both natural and human-induced disturbance, but human-mediated disturbance is now the most serious cause of seagrass loss worldwide (Sargent et al. 1995; Short and Wyllie-Echeverria 1996). Reduction in water clarity and quality and physical damage by motor vessels are some of the most common negative impacts of human activities on seagrass beds (Sargent et al. 1995). Motor vessels are implicated in seagrass bed damage in a number of ways, including anchoring (Walker et al. 1989; Hastings et al. 1995; Creed and Filho 1999), propeller scarring (Fig. 1) (Zieman 1976; Durako et al. 1992; Dawes et al. 1997; Dunton and Schonberg 2002; Kenworthy et al. 2002), and large excavations caused by vessel groundings (Whitfield et al. 2002; Fonseca et al. 2002). In 1995 it was estimated that 30,000 acres of seagrass beds in the Sanctuary were moderately to severely scarred by boat propellers (Sargent et al. 1995).

Figure 1. Aerial photograph of a shallow seagrass bank severely scarred by boat propellers.

Propeller scar damage disrupts the seagrass rhizome matrix and excavates sediments, leaving behind unvegetated trenches that may be up to 40 cm deep, 50 cm wide, and hundreds of meters long. Once the damage occurs, wind-, wave-, and current-induced erosion may further enlarge these trenches, creating injuries that heal very slowly, taking years to decades to recover (Zieman 1976; Durako et al. 1992; Dawes et al. 1997; Kenworthy et al. 2002; Whitfield et al. 2002). The resulting habitat fragmentation may negatively impact macrofauna that utilize seagrass beds (Bell et al. 2001; Uhrin and Holmquist 2003), thereby compounding the damage to seagrass ecosystems. Increased population density along U.S. coasts and subsequent increased boating activity will place additional burdens on seagrass resources. Natural resource managers therefore require restoration tools that can be implemented in a timely fashion and at reasonable cost to repair damage to seagrass communities.

Seagrass Recovery, Inc., a private company based in Ruskin, FL, has created and patented the Sediment Tube®, a biodegradable cotton tube that is filled with sediment and laid directly into a propeller scar (Fig. 2). A single tube is approximately 1.5 m long, 15-20 cm in diameter, and weighs 13.6-18.2 kg when filled with crushed calcium carbonate screening sand. The sediment tubes serve three possible functions: 1) to restore propeller scars to grade; 2) to deliver a desired sediment grain size; and 3) to prevent further erosion of the scar by water flow (Fig. 3). The objective of this project was to test this method of propeller scar restoration in a variety of energy regimes and sediment types. We also combined sediment tubes with bird stakes, a proven method of enhancing growth of colonizing seagrass species (Powell et al. 1989; Powell et al. 1991; Fourqurean et al. 1995; Kenworthy et al. 2000).

Figure 2. Filled sediment tubes ready to be deployed.

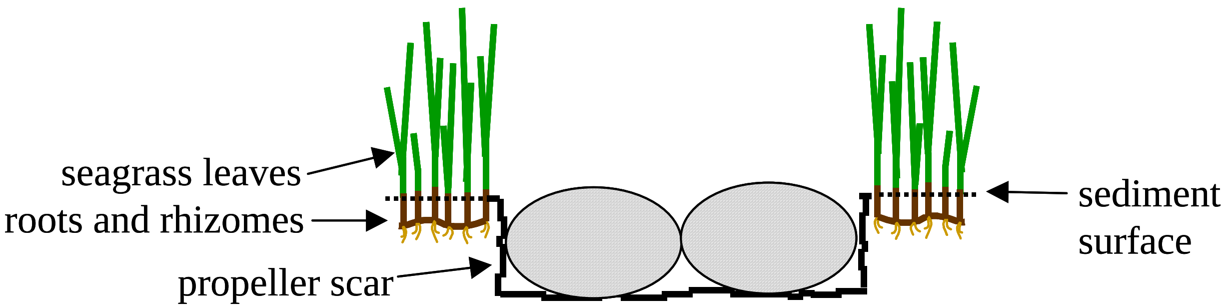


Figure 3. Cross-sectional view of sediment tube deployment into an existing propeller scar.

Study Site

The study was conducted in the Lignumvitae Key Management Area in the FKNMS. The 4,050 ha park, located in the middle region of the Florida Keys (Fig. 4), is comprised of many shallow seagrass banks dominated by *Thalassia testudinum* and is a popular destination for recreational flats fishers.

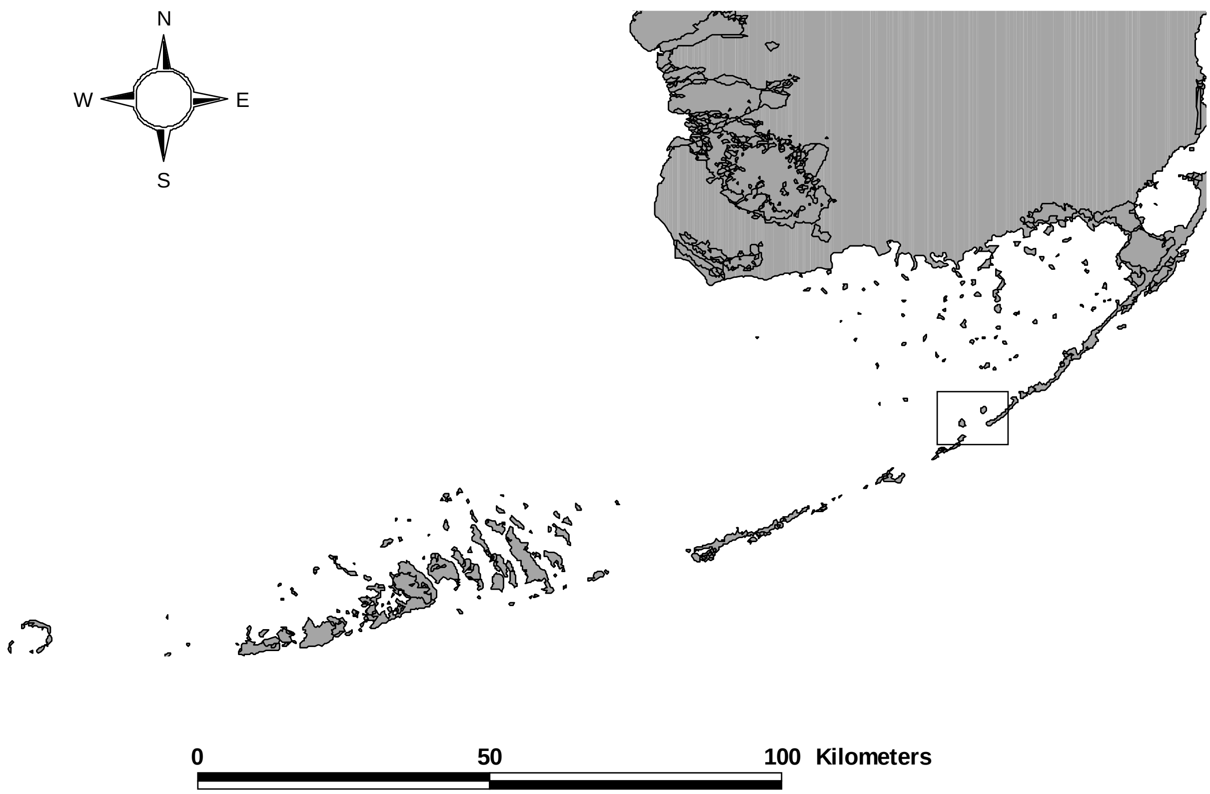


Figure 4. The experiment was deployed in the Lignumvitae Key Management Area within the Florida Keys National Marine Sanctuary. The area delineated by the box is enlarged in Figure 5.

The tidal range within the park is approximately 1 m, and the seagrass habitat outside the navigation channels is vulnerable to boat traffic during most of the tidal cycle. In 1993, after extensive motor vessel damage to seagrasses, approximately 2,430 ha of seagrass meadows within the park were protected by the creation of permanent combustion engine exclusion zones. Boaters can still access these exclusion zones in kayaks, canoes, and sailing craft; with trolling motors, and by poling with engines tilted up and turned off. Although legitimate boat channels are clearly marked within the park, local fishing guides have created “wheel ditches,” or propeller scars that have eroded to form new channels in an effort to avoid traveling around the shallow seagrass banks. Injuries also occur when boaters unfamiliar with the area, who do not know how to read charts, posted signs, or the natural landmarks, accidentally go aground on the shallow banks. Park managers and the FKNMS continue to be concerned about the loss of seagrass habitat and are seeking new cost-effective and straightforward ways to restore damaged meadows.

Sixteen scars within the preserve were selected (Fig. 5) in four areas: Indian Key (IK), Lignumvitae Key (LV), Soft Indian Key (SIK), and Shell Key (SK). The IK area is on the ocean side, adjacent to the high-traffic Indian Key Channel, and exposed to easterly trade winds. Sediments at the IK area are composed of *Porites* sp. coral rubble and coarse carbonate sand.

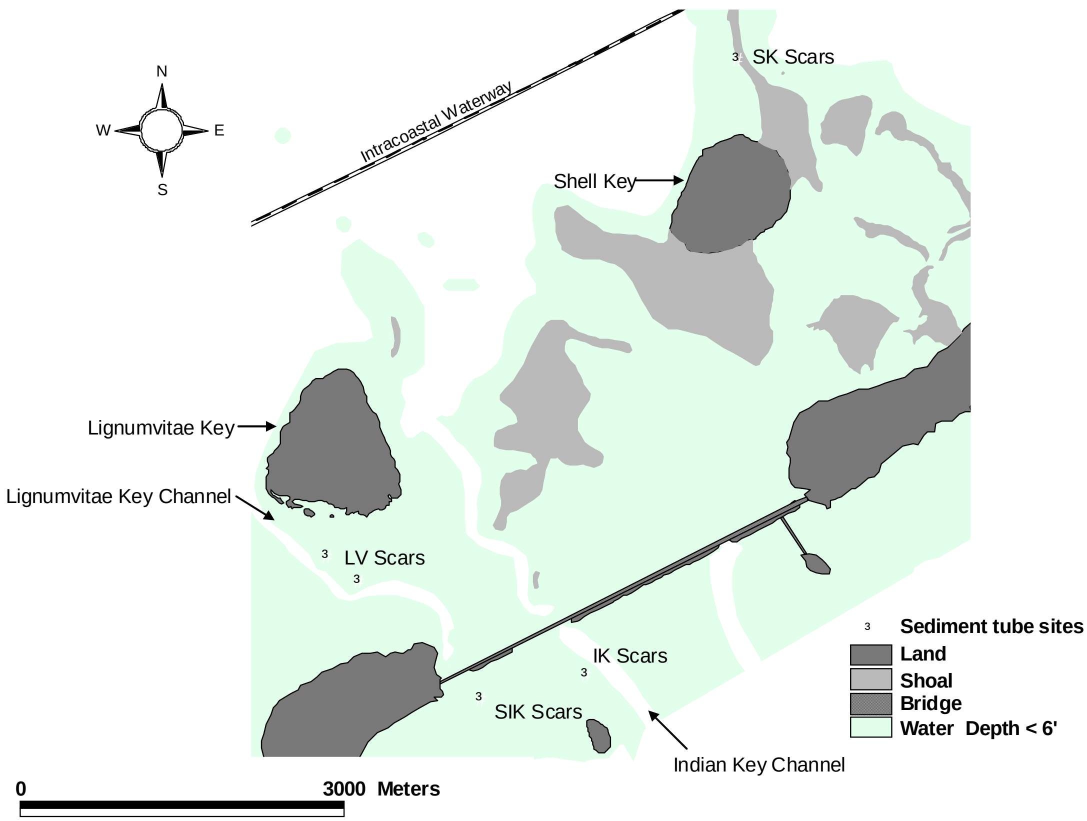


Figure 5. Lignumvitae Key Management Area. Sixteen scars were chosen in four areas of the management area.

The LV area is adjacent to the well-traveled Lignumvitae Key Channel, but is on the bay side, protected by a bridge, and has little exposure to the easterly fetch. Sediment at the LV area is composed of fine carbonate mud. The SIK area is also on the ocean side, but on the more protected west side of the seagrass bank. SIK sediment is primarily fine carbonate mud. The SK area is on the bay side and is partially sheltered from easterly winds, but is exposed to northeast winds. The SK sediment type is coarse coral rubble. The scar locations were chosen to encompass a wide range of sediment types, wave exposures, and energy regimes. Four scars were treated in each area for a total of 16 replicate scars.

Experimental Design

Treatments included: 1) sediment tubes with bird stakes and transplants, 2) bird stakes with *Halodule wrightii* bare-root transplants, 3) sediment tubes only, and 4) controls (no treatment) (Fig. 6). Replicate propeller scars were 30-50 m long, approximately 40 cm wide and 15-20 cm deep. Distance between replicate scars ranged from < 10 to > 6,000 m. In each scar, four treatments were randomly assigned to 3 m sections separated by 3 m sections of untreated scar. Thus each scar contained four experimental units: 1) a 3 m sediment tube unit, 2) a 3 m bird stake + planting unit, 3) a 3 m sediment tube + bird stake + planting unit, and 4) a 3 m control unit. This was repeated in each replicate scar, for a total of 16 replicates for each treatment.

Sediment tubes were filled by hand, using a funnel and a shovel. The sediment fill was composed of native crushed carbonate screening sand. Sediment grain size ranged from 0.063 to greater than 0.85 mm, with approximately 45% of the sediment particles $\geq$ 0.85 mm in diameter. Approximately 5% of the sediment was very fine silt. Filled tubes were loaded onto a shallow-draft vessel and motored out to deployment sites. At the sites, each tube was lowered into the water near a propeller scar and then maneuvered into place (Fig. 7). Each sediment tube treatment required four tubes to complete the tube treatment (see Fig. 6).

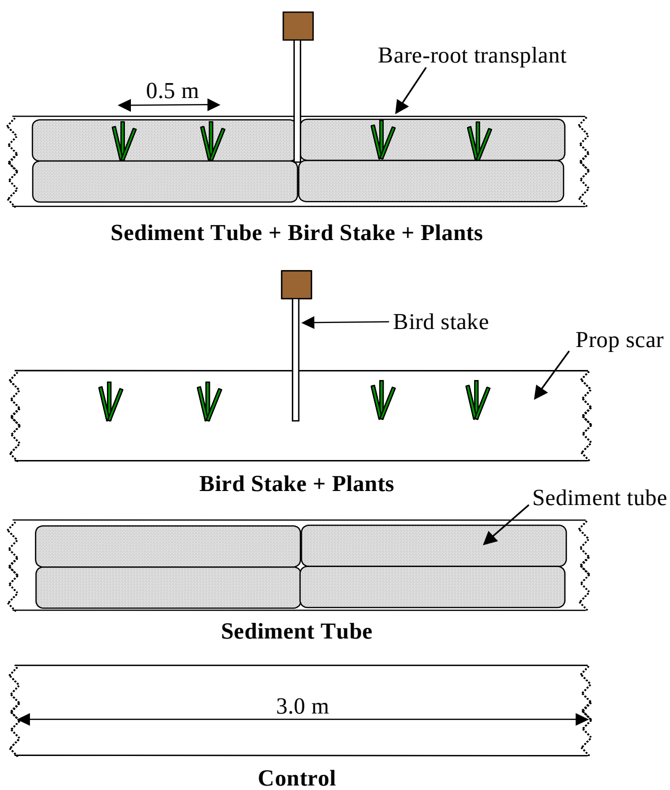


Figure 6. Experimental design. One of each treatment was deployed into each replicate prop scar.

Bird stakes were created by mounting blocks of pressure-treated lumber (approximately 10 cm x 9 cm x 4 cm thick) onto 3 m lengths of 2 cm PVC (1/2”). The bird stakes were driven into the substrate until the blocks were about 1-1.5 m above the substrate, so the blocks would be just above the water surface at mean high tide. A planting unit was composed of 3-5 runners of *Halodule wrightii*, each bearing at least five short-shoots and one apical meristem. Bird stakes were placed in the center of the treatment, 1.5 m from either treatment end, and the planting units were placed at 50 and 100 cm intervals from the center bird stake (Fig. 6). When planting in a sediment tube, we used a dive knife to create a hole into which we inserted the planting unit, slitting about 5-10 cm of the fabric to allow horizontal rhizome growth into the tube. For "bird stake + plants" treatments, the planting units and bird stakes were spaced as above, and the planting units were inserted directly into the sediment.

Figure 7. A shallow draft vessel was maneuvered close to the propeller scar and the sediment tubes were lowered into place.

The experiment was deployed in June 2001 and monitored in September 2001, February 2002, August 2002, and May 2003. Surveys included visual assessment of seagrass and macroalgal cover within the scar and in the adjacent, undisturbed seagrass bed, measurement of scar width, and digital video transects along the entire length of each experimental unit. Cover was assessed using a Braun-Blanquet scale of 0 (no cover) to 5 (> 75% cover) (Fourqurean et al. 2001). The middle 2.5 m of each treatment was surveyed using five 50 cm x 35 cm quadrats placed end to end to assess contiguous sections of the treatment. Adjacent seagrass cover was assessed in a 50 cm x 50 cm quadrat placed perpendicular to the scar treatments at a distance of 1 m into the undisturbed seagrass. Two quadrats were assessed for each treatment, one on each side, for a total of eight adjacent quadrats per scar. The replicate quadrats were averaged to obtain one value for each treatment in each scar. Adjacent quadrats were treated in the same manner. In May 2003, in addition to Braun-Blanquet assessments, we also counted the number of *Halodule wrightii* short-shoots in each treatment. Because we used several quadrat sizes (50 cm x 50 cm, 35 cm x 50 cm, and 10 cm x 10 cm), all values were standardized to short-shoots per square meter for comparison between treatments and with values reported in the literature.

Initial scar width was recorded in several positions along the scar in June 2001. In September 2001 and August 2002, two treatment widths were measured, each 1 m from treatment ends, by laying a meter stick perpendicular to the treatment and measuring the width of unvegetated scar or treatment. Thus if seagrass began to grow into the scar from the injury margins, the width of the scar would decrease.

Data Analysis

Visual assessment data were compiled using linear regression. The recovery trajectory of three variables (*Thalassia testudinum* cover, *Halodule wrightii* cover, and total seagrass cover) in the adjacent seagrass bed and within each treatment and scar was plotted as a function of time. After satisfying assumptions of variance homogeneity and normal distribution of the data, the *T. testudinum* and total seagrass slopes generated by these regressions were used as new variables in a one-way analysis of variance testing the effect of treatment on scar recovery trajectory. Pair-wise comparisons were conducted among treatments using Tukey's studentized range tests. Transformation of *H. wrightii* slopes failed to resolve issues of non-normality and variance heterogeneity, so nonparametric Kruskal-Wallis tests were used to examine treatment effect on *H. wrightii* recovery trajectory and in paired treatment comparisons for recovery trajectory. A Kruskal-Wallis test was used to examine treatment effect on scar width, as well as to conduct pair-wise comparisons between treatments.

One-way analysis of variance was used to examine cover differences among treatments in May 2003, two years after deployment, for *Thalassia testudinum* and total seagrass. Differences in cover of *Halodule wrightii* in May 2003 were examined using Kruskal-Wallis tests due to data non-normality and variance heterogeneity. May 2003 *H. wrightii* shoot counts were natural log transformed to meet assumptions of normality and variance homogeneity and treatments were compared using one-way analysis of variance and a Tukey's studentized range test.

Results

A few bird stakes had to be replaced, but no other treatments were damaged during the study. Rhizophytic macroalgae quickly recruited to the sediment tubes (Fig. 8). Sediment tube fabric had begun to break down by September 2001, three months after deployment. By August 2002, only the seam portions of the sediment tubes were apparent and we did not find any evidence of fabric during the May 2003 survey. Despite the degradation of the fabric, most of the carbonate sand remained in the scars throughout the duration of the study. Recovery within scars was variable. Some scars reached total seagrass cover equal to the surrounding, undisturbed seagrass bed after two years, while other scars fared much worse and still had low cover values two years after treatment. The wide range of recovery rates caused very high variability about the recovery trajectories.

One-way analyses of variance revealed a significant effect of treatment on *Thalassia testudinum* cover and total seagrass cover ($p < 0.0001$ for both analyses, Table 1). Pair-wise comparisons showed that the only significant comparisons were between the adjacent, undisturbed seagrass bed and the treatments inside the scars (Fig. 9 and 10). There were no differences in recovery rates of control, sediment tube, sediment tube + bird stake + planting units, and bird stake + planting units treatments for either *T. testudinum* or total seagrass cover.

Figure 8. Macroalgae and *Halodule wrightii* planting units in a sediment tube treatment in September 2001, three months after deployment.

Table 1. Analysis of variance and Kruskal-Wallis results for *Thalassia testudinum* (TT), total seagrass (TSG), and *Halodule wrightii* (HW) recovery trajectory analyses.

Dependent Variable	Independent variable	DF	F-value/Chi-Square value	P-value
TT	treatment	4	6.98	< 0.0001
TSG	treatment	4	9.99	< 0.0001
HW	treatment	4	21.82	0.0002

Kruskal-Wallis tests results for *Halodule wrightii* cover demonstrated a significant treatment effect on recovery trajectory (Fig. 11). Pair-wise comparisons revealed that the two treatments that included bird stakes showed higher recovery trajectories than the non-bird stake treatments, and the bird stake treatments were not significantly different from each other (Fig. 11). The significant differences resulted from the presence and continued growth of the *H. wrightii* planting units. Variability in cover was high in the bird stake treatments. There was a trend of increasing cover over time. Although mean *H. wrightii* cover never exceeded 5%, cover in some individual quadrats was greater than 75% (Braun-Blanquet value of 5) in surveys conducted in May 2003.

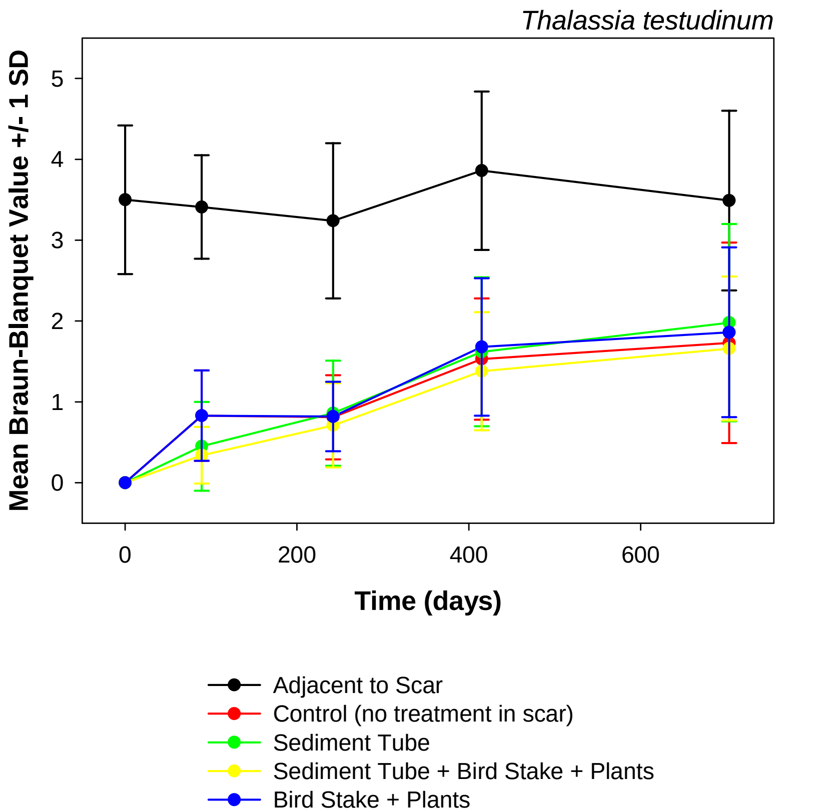


Figure 9. *Thalassia testudinum* recovery trajectories.

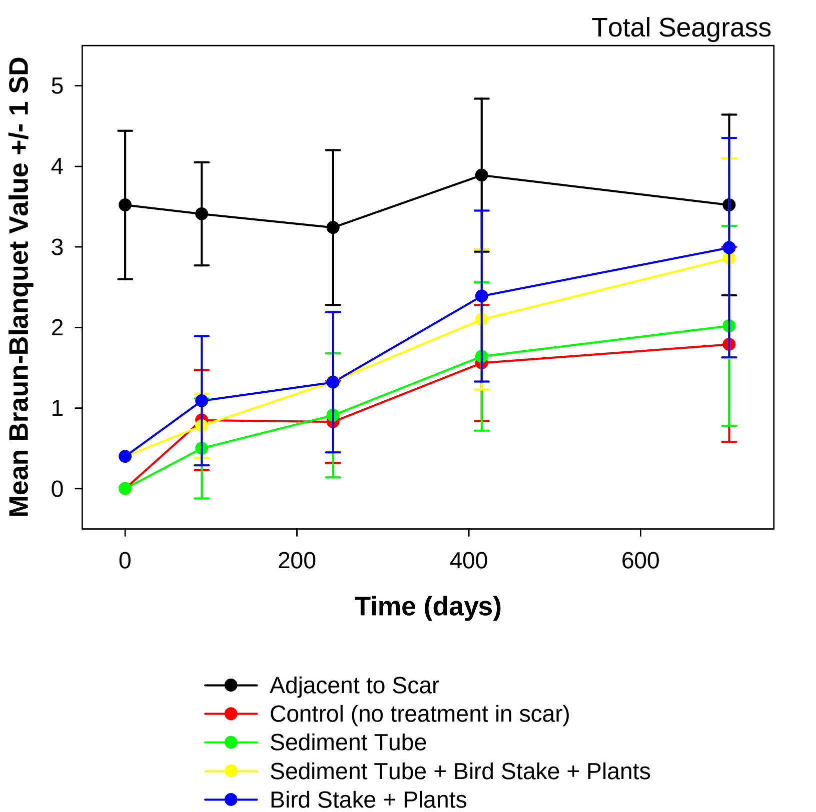


Figure 10. Total seagrass recovery trajectories.

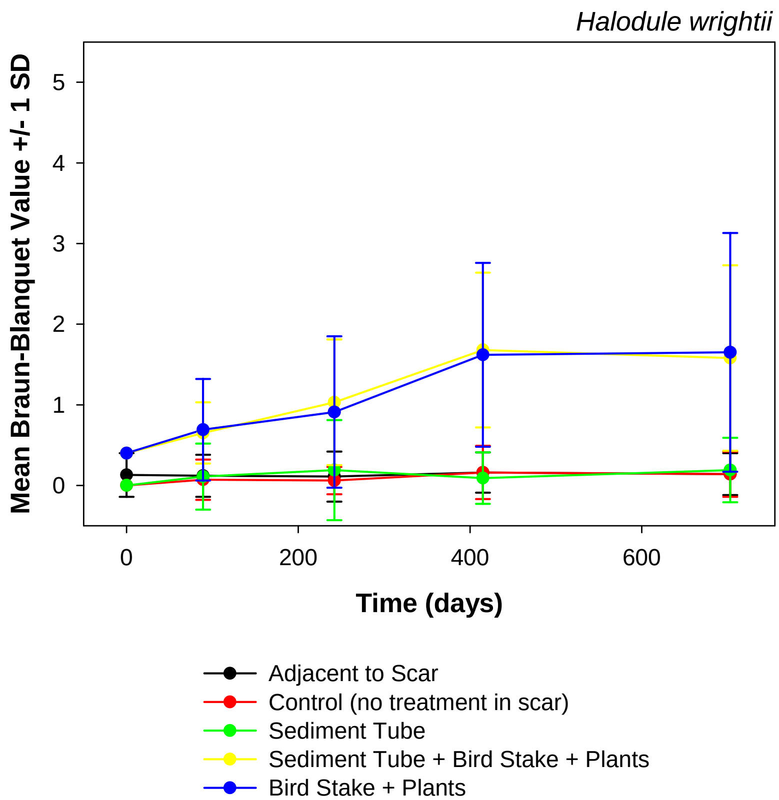


Figure 11. *Halodule wrightii* recovery trajectories.

Initial scar width was 41.8 cm (sd = 12.02), and this declined to 27.0 cm (sd = 22.7) after two years. A Kruskal-Wallis comparison of propeller scar widths measured in treatments three months and 14 months after deployment revealed a significant effect of treatment on scar width ($p = 0.024$). Pair-wise comparisons demonstrated that scar widths were significantly smaller in the bird stake + plants treatment than control and sediment tube treatments. The two bird stake treatments were not significantly different from each other, and the control and sediment tube treatments were also not significantly different from each other (Fig. 12). These results demonstrate that although cover of seagrasses was low, there was some evidence that bird stake treatments caused increased growth of *Halodule wrightii* planting units within scars and *Thalassia testudinum* from injury margins, resulting in decreased scar width.

One-way analysis of variance conducted in May 2003, 23 months after deployment, on *Thalassia testudinum* cover revealed that there were no treatment differences within scars, but that adjacent, undisturbed *T. testudinum* cover was significantly higher than *T. testudinum* cover inside scars ($p < 0.0001$, Table 2). There also were significant differences in total seagrass cover in May 2003 ($p = 0.0012$, Table 2). Adjacent total seagrass cover was significantly greater than control or sediment tube total seagrass cover, but no other pair-wise comparisons were significant. Kruskal-Wallis analyses on *Halodule wrightii* cover for May 2003 demonstrated that bird stake treatments, which were not significantly different than each other, were significantly greater than adjacent, control and sediment tube only treatments ($p < 0.0001$, Table 2). Short-shoot counts of *H. wrightii* ranged from 4.0 m^{-2} in the adjacent, undisturbed seagrass bed to

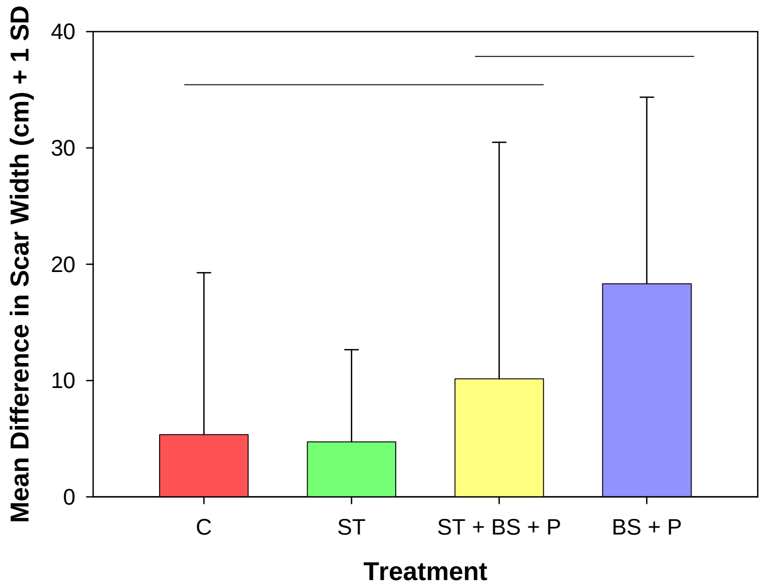


Figure 12. Mean change in scar width. C = control, ST = sediment tube, ST + BS + P = sediment tube + bird stake + plants, and BS + P = bird stake + plants. Lines over the bars indicate significant differences.

Table 2. Analysis of variance and Kruskal-Wallis results for May 2003 *Thalassia testudinum* (TT), total seagrass (TSG), and *Halodule wrightii* (HW) cover and *H. wrightii* short-shoot density (HWSS).

Dependent Variable	Independent variable	DF	F-value/Chi-Square value	P-value
TT	treatment	4	7.48	< 0.0001
TSG	treatment	4	5.06	0.0012
HW	treatment	4	32.64	< 0.0001
HWSS	treatment	4	19.58	< 0.0001

1,130 m^{-2} in the sediment tube + bird stake + planting unit treatment in May 2003 (Fig. 13). One-way analysis of variance for *H. wrightii* shoot density was significant ($p < 0.0001$, Table 2). Pair-wise comparisons of the shoot density data revealed that the two bird stake treatments had significantly higher *H. wrightii* shoot densities than the other three treatments, which were not significantly different from each other (Fig. 13).

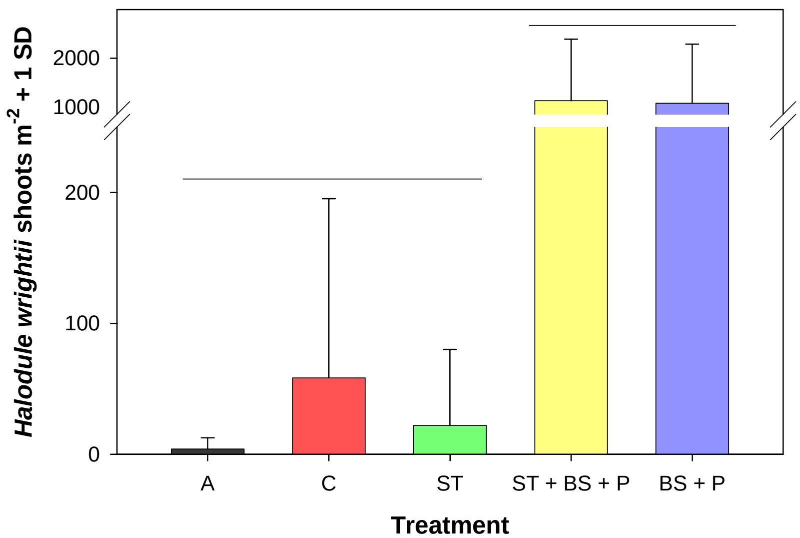


Figure 13. May 2003 *Halodule wrightii* shoot densities. A = adjacent to scar, C = control, ST = sediment tube, ST + BS + P = sediment tube + bird stake + plants, and BS + P = bird stake + plants. Lines over the bars indicate significant differences.

Discussion

The high level of variability in seagrass recovery resulted in no significant improvement in seagrass recovery trajectory due to the sediment tube and bird stake treatments, alone or in conjunction. Our observations revealed that sediment tubes were an effective means of deploying fine sediments into propeller scars, but the presence of tubes did not enhance seagrass growth into the scars from the scar margins. The addition of fertilizer in the form of bird feces (Fig. 14), when coupled with sediment tubes, did not enhance total seagrass or *Thalassia testudinum* recovery trajectories. In May 2003, two years after deployment, *T. testudinum* cover inside the propeller scars still had not reached the levels of *T. testudinum* cover in the adjacent, undisturbed seagrass bed. While the results for total seagrass cover analysis on May 2003 data were somewhat different, the differences are attributable to the *Halodule wrightii* planting units coupled with bird stakes, which also influenced results of the *H. wrightii* May 2003 comparison. In all cases, the high degree of variability in seagrass cover resulted in no one experimental treatment significantly outperforming another. Conversely, presence of sediment tubes did not slow recovery, and we frequently observed seagrass shoots emerging from sediment tube treatments (Fig. 15). Also worth noting is that we used conditions in adjacent, undisturbed seagrass beds as a measure of what recovery in the scars should look like, yet those conditions varied from 25 to 75% cover. Our inability to more precisely quantify what comprises ideal recovery is due to the use of the Braun-Blanquet visual assessment technique, which has broad ranges of cover for each numerical category. This assessment technique may not have the necessary resolution to detect subtle differences, but it does detect larger differences and is a cost-effective and repeatable method of visual assessment (Fourqurean et al. 2001).

Figure 14. Cormorants roosting on bird stakes.

Figure 15. *Thalassia testudinum* short shoot (arrow) growing in a sediment tube treatment.

Scar width decreased from a mean of 41.8 cm to a mean of 27.0 cm two years later. There was some evidence that bird stake treatments may have enhanced seagrass growth enough to affect the width of scars, but not enough to significantly increase total seagrass cover within scars. Variability in scar widths was much greater in August 2002 than at the beginning of the study, suggesting that seagrass growth from the scar margins was occurring in a patchy manner, perhaps driven more by processes acting at the local level than by the treatments themselves.

Recovery estimates of propeller scars in healthy monospecific *Thalassia testudinum* beds range from 3.5 to 9.6 years (Durako et al. 1992; Dawes et al. 1997; Kenworthy et al. 2002). In a similar study conducted within the Lignumvitae Key State Botanical Preserve, Kenworthy et al. (2002) predicted that scars in *T. testudinum* beds would recover in 5.4 to 9.6 years based on data collected on 1-2 year old scars followed for 18 months. In fact, 1-2 years may be required for *T. testudinum* to begin to form new rhizome apical meristems and initiate growth at scar margins (Zieman 1976).

Zieman (1976) and Kenworthy et al. (2002) postulate that several factors may cause the slow recovery of *Thalassia testudinum* in propeller scars. First, the action of the propeller excavates sediment and severs rhizomes. If new sediment is deposited in the scar, it will for a time be relatively devoid of organic material and the sediment chemistry may be different than that of surrounding healthy seagrass beds (Zieman 1976; but see Dawes et al. 1997). In some cases, the energy and current regime is such that sediments will be further scoured from the original injury, thereby exacerbating sediment loss (Whitfield et al. 2002). Disruption of and damage to rhizomes requires that new apical meristems be formed (Zieman 1976; Dawes et al. 1997), a process that requires time in a slow-growing species such as *T. testudinum*. Once rhizomes are exposed at the margins of the scar, they may be less likely to grow due to light exposure and may not possess the architecture necessary to grow down into the remaining sediment (Marba et al. 1994; Duarte et al. 1997; Kenworthy et al. 2000).

Because of the clonal integration exhibited by *Thalassia testudinum*, changes in sediment chemistry probably did not significantly impact short-term recovery. New vegetative growth from scar margins is more likely to rely on nutrient resources translocated from the intact rhizome than resources absorbed by the actively growing root and rhizome tissue. Thus it is not surprising that the bird stake treatments did not result in higher rates of recovery for *T. testudinum* over the course of this study. In fact, given the slow rhizome elongation rates for *T. testudinum*, we might not see significant recovery after 23 months even under optimal conditions, as evidenced by control treatments that were significantly lower in cover than adjacent treatments in all scars.

There is evidence that sediment tubes do not prevent seagrass from growing into scars (Table 2). In fact, in most cases the sediment tube and sediment tube + bird stake combinations performed about the same (Fig. 9 and 10), although sediment-tube-only treatments did not always attain seagrass coverage equivalent to that of adjacent, undisturbed seagrass beds (Fig. 10). Sediment tubes did allow for the introduction of fine-grained sediment to fill scars, and in high energy environments this sediment would likely get washed away by water flow were it not encased in a sediment tube. Fine-grained sediments are typically found in mature, well developed seagrass beds and are a much better substrate for tropical seagrass growth than coarser sediments. Roots and rhizomes are more easily anchored into finer sediments while the smaller grain size promotes the retention of organic matter and nutrients needed to support seagrass growth, rhizome expansion, and formation of new shoots. In addition, sediment tubes probably would prevent further erosion from occurring in propeller scars in storm events, although we did not test this hypothesis and no significant storm events occurred over the course of the study.

Halodule wrightii is a good choice for transplanting for a number of reasons. It is a smaller-bodied seagrass than *Thalassia testudinum*, which makes it easier to handle the planting units and concentrate apical meristems in those planting units. *Halodule wrightii* is also a faster-growing species that frequently and opportunistically colonizes disturbed areas (Kenworthy et al. 2002). The use of bird stakes and planting units has been shown to enhance growth of *H. wrightii* (Powell et al. 1989; Powell et al. 1991; Fourqurean et al. 1995; Kenworthy et al. 2000). The results of this experiment show that in some cases effects of the sterility of the sediment tube fill is offset by the addition of nutrients in the form of bird feces (Fig. 11 and 13). *Halodule wrightii* short-shoot counts in the bird stake treatments reached 1,076 and 1,130 m^{-2} in May 2003, nearly two years after deployment. These *H. wrightii* shoot densities are in the lower range of densities reported in another bird stake study in the Lignumvitae Key Management Area. Kenworthy et al. (2000) reported densities of 1,000-3,700 m^{-2} in planted bird stake treatments two years after deployment. The fact that *H. wrightii* densities were similar in treatments with and without sediment tubes, and similar to densities in a previous experiment, adds weight to the argument that sediment tubes do not prevent regrowth of seagrass into scars when coupled with bird stakes. Use of bird stakes allows for "compressed succession," in which the faster growing *H. wrightii* temporarily fills in unvegetated propeller scars, to be replaced eventually by the slower growing *T. testudinum*.

Summary and Recommendations

Based on the results of this study we conclude: 1) sediment tubes are a clean and efficient means of deploying fine grained sediments into excavations in seagrass beds; 2) *Halodule wrightii* can be transplanted into sediment tubes; 3) sediment tubes degrade fast enough to allow for growth of seagrass transplants; and 4) sediment tubes do not inhibit *Thalassia testudinum* growth or algal colonization. Given these results, we recommend that sediment tubes be tested for use in larger blowholes where lateral growth of seagrass into excavated injuries is very slow (Whitfield et al. 2002; Kenworthy et al. 2002; Fonseca et al. 2002). Some larger blowholes associated with vessel groundings take >5-10 years to recover and will be exposed to the destabilizing effects of severe storms and further degradation without some form of stabilization and rehabilitation. In restoration plans being developed for the NOAA Mini 312 Seagrass Damage Assessment and Restoration Program we presently recommend filling and stabilizing large blowhole injuries with carbonate pea rock (6-7 mm diameter). Although the larger sized pea rock will provide a stable substrate suitable for seagrass growth (Kenworthy et al. next chapter in this report), the addition of fine-grained sediments introduced by capping the pea rock with a layer(s) of sediment tubes may actually enhance the growth of seagrasses, especially when coupled with the method of compressed succession. Fine-grained sediment in the tubes will percolate into the upper layer of pea rock as the tube material decomposes, improving the quality of the unconsolidated substrate for seagrass growth. By installing bird stakes with sediment tubes and adding *H. wrightii* transplants we may be able to obtain sediment-stabilizing cover of the faster-growing seagrass within two years, instead of waiting several years or even decades for seagrasses to grow in from the perimeter of a large injury.

Two previous studies (Kenworthy et al. 2000; Kenworthy et al. unpublished data) have documented the successful use of bird stakes in fine-grained sediments, but have never documented the use of bird stakes with pea rock alone. The next evaluation needed is a direct comparison between two restoration approaches to test the cost effectiveness of using sediment tubes: 1) fill replicated blowholes with pea rock, cap with sediment tubes, plant with *Halodule wrightii*, and add bird stakes; compare to; 2) fill replicated blowholes with pea rock, plant with *H. wrightii*, and add bird stakes. The second approach is presently what we propose in restoration plans where blowholes exceed an excavation depth of 20 cm. However, we have never compared pea rock alone with the sediment tubes, especially in high energy environments where regular wind turbulence and tides coupled with storm surge are such that blowholes are vulnerable to chronic and acute erosion (Whitfield et al. 2002). In these types of environments sediment tubes will restore the scars and blowholes to grade and diminish the area of eroded faces around the perimeter of the blowhole. Furthermore, by initially containing the fine-grained sediment in biodegradable fabric we minimize the potential for release of sediments and turbidity outside of the restoration site. Although untested, we predict that damage to seagrass beds in highly eroded areas would benefit from the use of sediment tubes, especially coupled with bird stakes and *H. wrightii (S. filiforme*) planting units. Sediment tubes may also be particularly useful in deeper water sites where deployment of any type of sediment with construction equipment is logistically difficult. Another possible use for sediment tubes recently suggested by Kevin Kirsch (NOAA Damage Assessment Center) is to deploy them in excavations filled with flocculent sediment with the intent to displace the flocculent material with firmer sediment more conducive to seagrass growth.

References

Bell, S.S., R.A. Brooks, B.D. Robbins, M.S. Fonseca, and M.O. Hall. 2001. Faunal response to fragmentation in seagrass habitats: implications for seagrass conservation. Biological Conservation 100: 115-123.

Creed, J.C., and G.M.A. Filho. 1999. Disturbance and recovery of the macroflora of a seagrass (*Halodule wrightii* Ascherson) meadow in the Abrolhos Marine National Park, Brazil: an experimental evaluation of anchor damage. Journal of Experimental Marine Biology and Ecology 235: 285-306.

Dawes, C.J., J. Andorfer, C. Rose, C. Uranowski, and N. Ehringer. 1997. Regrowth of *Thalassia testudinum* into propeller scars. Aquatic Botany 59: 139-155.

Duarte, C.M., J. Terrados, N.S.R. Agawin, M.D. Fortes, S. Bach, and W.J. Kenworthy. 1997. Response of a mixed Philippine seagrass meadow to experimental burial. Marine Ecology Progress Series 147: 285-294.

Dunton, K.H., and S.V. Schonberg. 2002. Assessment of propeller scarring in seagrass beds of the south Texas coast. Journal of Coastal Research 37: 100-110.

Durako, M.J., M.O. Hall, F. Sargent, and S. Peck. 1992. Propeller scars in seagrass beds: an assessment and experimental study of recolonization in Weedon Island State Preserve, Florida. *In*: Webb, F.J., Jr. (ed). Proceedings of the Nineteenth Annual Conference on Wetlands Restoration and Creation. Tampa: Hillsborough Community College, pp. 42-53.

Fonseca, M.S., P.E. Whitfield, W.J. Kenworthy, D.R. Colby, and B.E. Julius. 2002. Use of two spatially explicit models to determine the effect of injury geometry on natural resource recovery. Aquatic Conservation: Marine and Freshwater Ecosystems.

Fourqurean, J.W., A. Willsie, C.D. Rose, and L.M. Rutten. 2001. Spatial and temporal pattern in seagrass community composition and productivity in South Florida. Marine Biology 138: 341-354.

Fourqurean, J.W., G.V.N. Powell, W.J. Kenworthy, and J.C. Zieman. 1995. The effects of long-term manipulation of nutrient supply on competition between the seagrasses *Thalassia testudinum* and *Halodule wrightii* in Florida Bay. Oikos 72: 349-358.

Hastings, K., P. Hesp, and G.A. Kendrick. 1995. Seagrass loss associated with boat moorings at Rottnest Island, Western Australia. Ocean and Coastal Management 26: 225-246.

Kenworthy, W.J., M.S. Fonseca, P.E. Whitfield, K.K. Hammerstrom, and A.C. Schwarzschild. 2000. A comparison of two methods for enhancing the recovery of seagrasses into propeller scars: mechanical injection of a nutrient and growth hormone solution vs. defecation by roosting seabirds. Final report to the Florida Keys Restoration Trust Fund, Tavernier, Florida, September 2000. 40 pp.

Kenworthy, W.J., M.S. Fonseca, P.E. Whitfield, and K.K. Hammerstrom. 2002. Analysis of seagrass recovery in experimental excavations and propeller-scar disturbances in the Florida Keys National Marine Sanctuary. Journal of Coastal Research 37: 75-85.

Marba, N., M.E. Gallegos, M. Merino, and C.M. Duarte. 1993. Vertical growth of *Thalassia testudinum*: seasonal and interannual variability. Aquatic Botany 47: 1-12.

Powell, G.V.N., J.W. Fourqurean, W.J. Kenworthy, and J.C. Zieman. 1991. Bird colonies cause seagrass enrichment in a subtropical estuary: observational and experimental evidence. Estuarine, Coastal and Shelf Science 32: 567-579.

Powell, G.V.N., W.J. Kenworthy, and J.W. Fourqurean. 1989. Experimental evidence for nutrient limitation of seagrass growth in a tropical estuary with restricted circulation. Bulletin of Marine Science 44: 324-340.

Sargent, F.J., T.J. Leary, S.W. Crewz, and C.R. Kruer. 1995. Scarring of Florida's seagrasses: assessment and management. Florida Marine Research Institute Technical Report TR-1, Florida Marine Research Institute, St. Petersburg, FL, 37 pp.

Short, F.T., and S. Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. Environmental Conservation 23: 17-27.

Uhrin, A.V., and J.G. Holmquist. 2003. Effects of propeller scarring on macrofaunal use of the seagrass *Thalassia testudinum*. Marine Ecology Progress Series 250: 61-70.

Walker, D.I., R.J. Lukatelich, G. Bastyan, and A.J. McComb. 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. Aquatic Botany 36: 69-77.

Whitfield, P.E., W.J. Kenworthy, M.J. Durako, K.K. Hammerstrom, and M.F. Merello. 2002. Recruitment of *Thalassia testudinum* seedlings into physically disturbed seagrass beds. Marine Ecology Progress Series.

Zieman, J.C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. Aquatic Botany 2: 127-139.

The Effect of Excavation Depth and Filling on Seagrass Recovery in Experimental Injuries in the Florida Keys National Marine Sanctuary

W. Judson Kenworthy, Kamille Hammerstrom, and Paula E. Whitfield (NOAA/NOS/NCCOS Center for Coastal Fisheries and Habitat Research, Beaufort, NC)
Manuel Merello (Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, St. Petersburg, FL)

Project Description
Greater understanding of the factors affecting seagrass recovery in propeller scars and small injuries is necessary to begin to restore damage to Florida Keys National Marine Sanctuary (FKNMS) resources. This project used experimental manipulation to assess effects of excavation depth and filling/regrading with carbonate pea rock on seagrass recovery into simulated propeller scars. We followed replicate experimental treatments for three years to track changes in *Thalassia testudinum* and *Syringodium filiforme* short-shoot density and macroalgal cover. Results will be used by resource managers to take appropriate measures for planning and implementing restoration of damaged tropical seagrass communities.

Introduction
Propeller scars and vessel groundings excavate sediments and disrupt seagrass rhizomes, leaving behind unvegetated trenches that may be up to 1- 2 m deep, several meters wide, and hundreds of meters long. In addition to the loss of fine sediments and organic material, *Thalassia testudinum* is not well adapted to growing at the steep injury margins created by vessel groundings (Zieman 1976; Kenworthy et al. 2002; Whitfield et al. 2002). *Thalassia testudinum* has thick, relatively inflexible horizontal and vertical rhizomes with meristems that normally remain buried beneath the sediment surface. *Thalassia* vertical rhizome apical meristems are organized to grow upward, ensuring that leaves are exposed to light. Exposure of apical meristems to light diminishes their activity, ensuring the correct position of photosynthetic leaves without exposing meristems. This rhizome morphology and the physiological response of meristems to light exposure is not conducive to vertical downward growth at steep topographical features like those created along the margins of vessel excavations. Furthermore, when sediment excavation and damage to rhizomes occurs, wind, wave, and current-induced erosion may further enlarge trenches, creating injuries that heal very slowly or are periodically reinjured by storms (Zieman 1976; Durako et al. 1992; Dawes et al. 1997; Kenworthy et al. 2002; Whitfield et al. 2002). In some cases the injuries may actually expand. The resulting habitat fragmentation may negatively impact macrofauna that utilize seagrass beds (Bell et al. 2001; Uhrin and Holmquist 2003), thereby compounding the damage to seagrass ecosystems.

Increased population density along United States coastlines and subsequent growth of boating activity will place additional burdens on seagrass resources. Natural resource managers therefore require restoration tools that can be implemented in a timely fashion and at reasonable cost to repair damage to seagrass communities.

This study was designed to address several factors impacting seagrass recovery in propeller scars and other small-scale disturbances. First is the question of excavation depth. Propeller scar depths vary widely depending on the vessel creating the injury as well as environmental characteristics of seagrass beds. The wide range of recovery times reported for propeller scars might be caused, in part, by differences in scar depth (Kenworthy et al. 2002). To this end, we designed an experiment to test the effect of excavation depth on seagrass recovery in simulated propeller scars. We created injuries 10, 20, and 40 cm deep and examined changes in injury depth as well as seagrass short-shoot density and macroalgal recovery as a function of time. As mentioned previously, injuries are vulnerable to expansion by erosion, so a second experiment was designed to test the effect of filling on recovery in simulated propeller scars. Using native limestone pea rock (6-7 mm diameter), we filled 30 cm excavations and compared their recovery to same-sized, but unfilled excavations. These two experiments addressed the following questions: 1) Is there a critical depth beyond which seagrasses would benefit from some sort of intervention to decrease recovery time (increase recovery rate)? 2) Does filling an injury with pea rock enhance or delay seagrass growth into the disturbed area, while protecting the injury from further erosion?

Study Site

Two experiments were deployed on a shallow seagrass-*Porites* sp. coral bank on the Gulf of Mexico side of Marathon Key in the Florida Keys National Marine Sanctuary (24.76^{o} N, 81.16^{o} W, Fig. 1). The bank system intercepts the flow of water through Moser Channel, one of the main

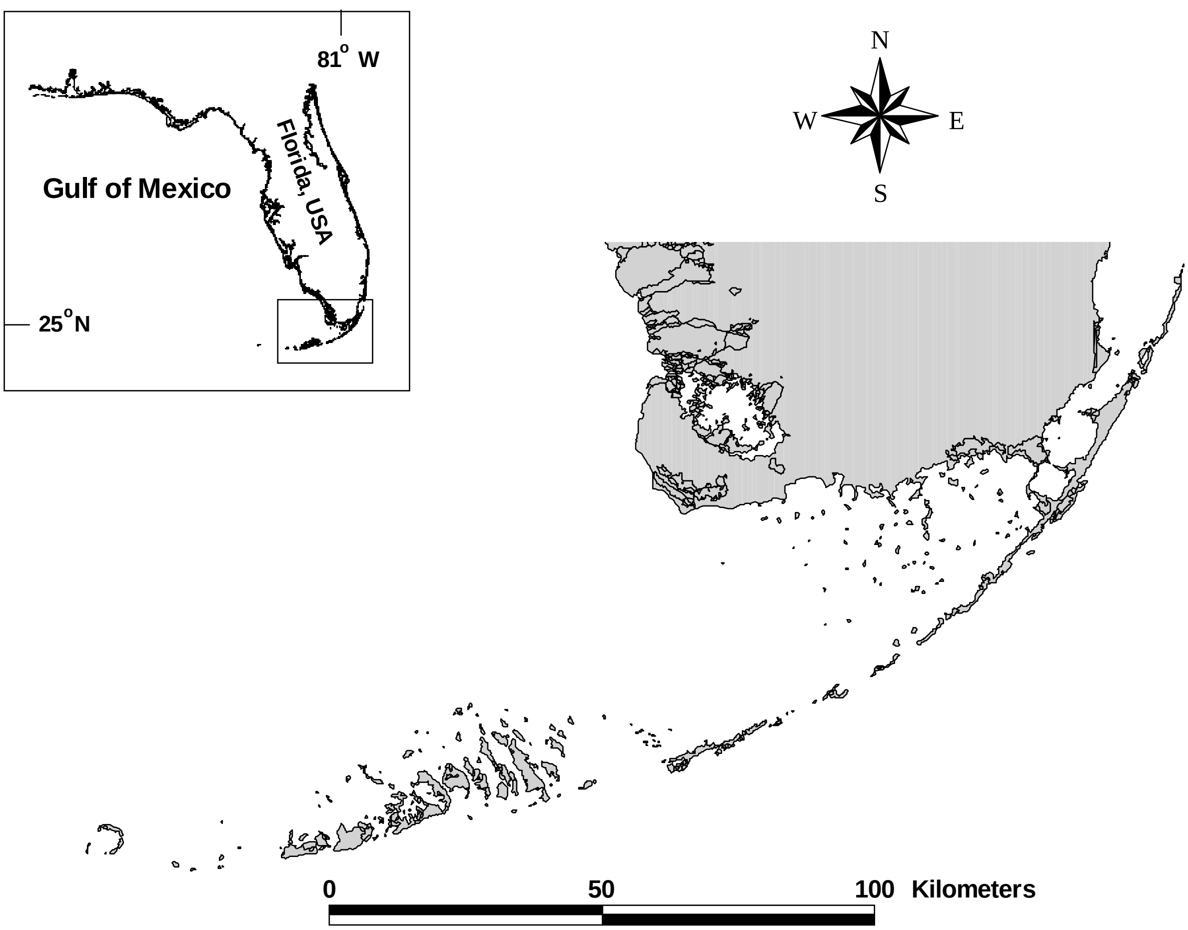


Figure 1. Study site. The area delineated by the box is enlarged in the lower right. The location of the excavation and fill experiments is labeled.

conduits connecting the Gulf of Mexico with the Florida Straits. The banks are raised 2 to 5 m above the surrounding bottom and were formed over several hundred years when the biotic communities physically stabilized a large volume of unconsolidated sediment. Because there is a net long-term transport of water from the Gulf of Mexico to the Florida Straits through Moser Channel (Smith 1994), these banks intercept sediments that are resuspended on the shallow shelf in the southeastern Gulf of Mexico. The large volume of material trapped and stored on these banks minimizes the southerly transport of suspended sediments and affords some protection for the coral reef tract to the south. Water depth on the bank top ranges from 10-15 cm at low tide to 1-1.5 m at high tide. Temperatures range from 9-23°C in the winter months (December-February) to 28-34°C in the summer months (June-August).

Experimental Design

Excavation Experiment

The excavation experiment was deployed in June 2000. Experimental plots were laid out haphazardly in an area of approximately 1,200 m^2 along a northwest-southeast axis, parallel to prevailing winds and perpendicular to tidal currents. Distance between plots ranged from 2 to 10 m, and most plots were approximately 5 m apart. Plots were surveyed seven times: September 2000, January 2001, May 2001, September 2001, January 2002, August 2002, and May 2003.

Five replicates each of four depth treatments (n = 20 replicates total) were deployed: (1) control (no sediment disturbance), (2) 10 cm, (3) 20 cm, and (4) 40 cm. Plot dimensions measured 50 x 150 cm. Positions of the plots were marked with polyvinyl chloride (PVC) and mapped using a differential global positioning system (DGPS). Control treatments were left undisturbed. The three other depth treatments were created by excavating above- and belowground biomass and sediments to the target depth using shovels and hoes (Fig. 2 and 3).

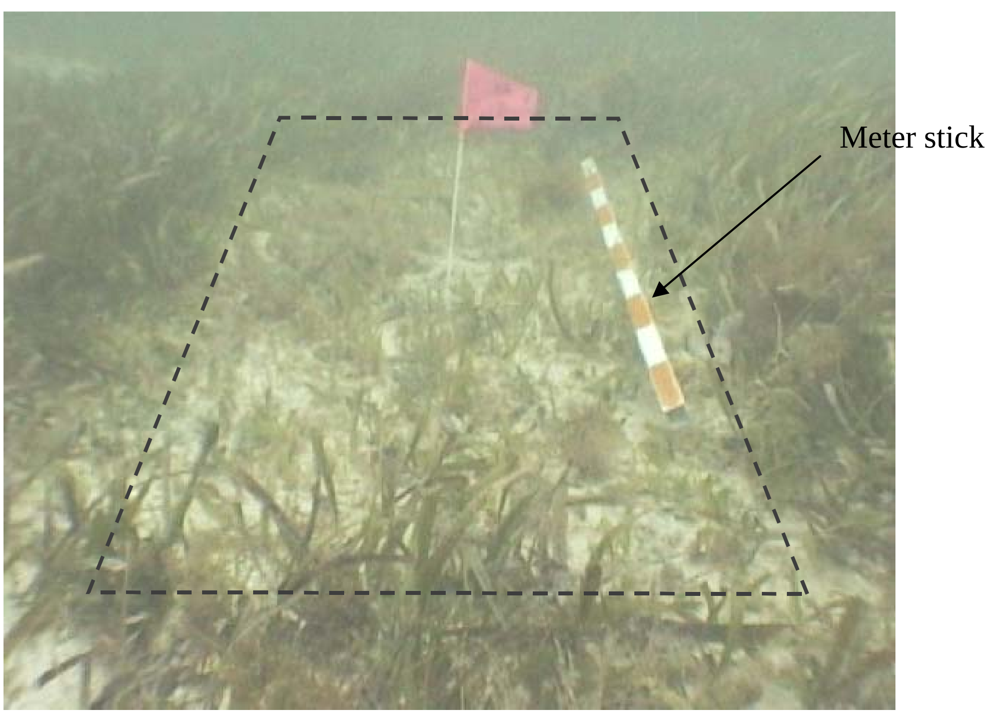


Figure 2. 10-cm treatment in June 2000, a few days after initiation. This depth treatment was created using hoes to scrape away the surface seagrass, macroalgae, and invertebrate biomass.

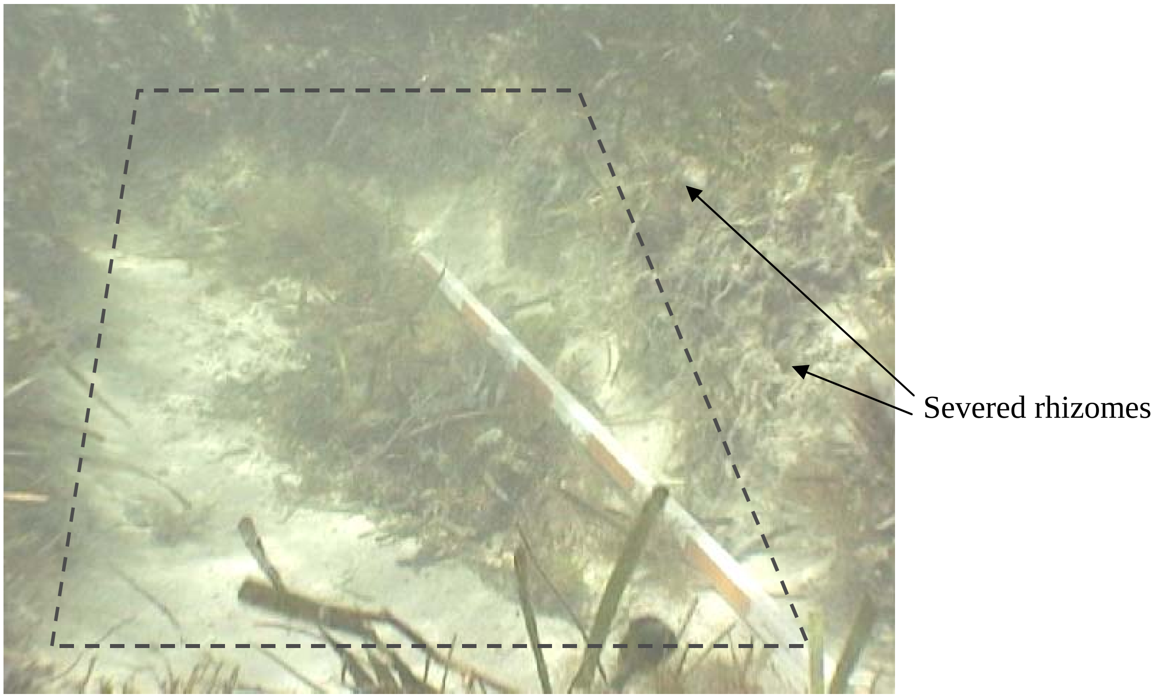


Figure 3. 40-cm treatment in June 2000, a few days after excavation. The 20- and 40-cm treatments were created with shovels. Excavated materials were removed in buckets. Injury margins have already started to collapse into the excavation. Drift algae has collected at the bottom.

During each survey period we collected the following data in each experimental treatment: (1) short-shoot counts of each seagrass species, (2) cover of seagrass and total macroalgae, (3) depth, and (4) video documentation. We evaluated cover of seagrasses and macroalgae using the Braun-Blanquet visual assessment method (Fourqurean et al. 2001). In this method, a numerical value is assigned based on the proportion of the total quadrat that is obscured by a species or functional group when observed from above (Table 1). Total macroalgae cover estimates encompassed all morphologies: upright fleshy, upright calcareous, and turf (Table 2).

Table 1. Braun-Blanquet cover scores. Each seagrass species and macroalgal functional group was scored in each quadrat according to this scale.

Score	Cover
0	Species/functional group absent from quadrat
0.1	Solitary short shoot or individual, < 5% cover
0.5	5 or fewer short shoots or individuals, < 5% cover
1	> 5 short shoots or individuals, < 5% cover
2	> 5 short shoots or individuals, 5-25% cover
3	> 5 short shoots or individuals, 25-50% cover
4	> 5 short shoots or individuals, 50-75% cover
5	> 5 short shoots or individuals, > 75% cover

Table 2. Species list of common macroalgae included in the total macroalgae Braun-Blanquet assessment.

Algal species	Morphology
Acanthophora sp., *Anadyomene stellata*, *Caulerpa* spp., *Dictyosphaeria cavernosa*, *Dictyota* spp., *Gracilaria* spp., *Halymenia* sp., *Hypnea cervicornis*, *Laurencia* spp.	upright fleshy
Acetabularia crenulata, *Avrainvillea nigricans*, *Halimeda* spp., *Penicillus* spp., *Rhizocephalus phoenix*, *Udotea flabellum*	upright calcareous
Amphiroa sp., *Batophera oerstedii*, *Chaetomorpha aerea*, *Dasycladus vermicularis*, turf form of *Halimeda opuntia*, *Neomeris annulata*	turf

Three 50 x 50 cm quadrats were placed end to end to evaluate the entire plot using the Braun-Blanquet visual assessment method. Short shoots were counted inside three randomly placed 25 x 25 cm quadrats in each plot. Twelve depths were recorded systematically from each plot. Depth was measured to the surface of the treatment from a reference pole placed across the treatment. Replicate measurements from each experimental plot were averaged and the mean plot value generated for each of these data types was used in further analysis.

Fill Experiment
The fill experiment was deployed in September 2000 about 25 m east of the excavation experiment on the same bank. Experimental plots were laid out along a northwest-southeast axis in a 300 m^2 area and spaced 2-3 m apart. Plots were arranged in a 3 x 6 array with treatments assigned randomly within each row. The experiment was surveyed seven times: January 2001, May 2001, September 2001, January 2002, May 2002, August 2002, and May 2003.

Six replicates of each of three fill treatments (n = 18 replicates total) were assigned to 50 x 150 cm plots: (1) control (no sediment disturbance), (2) fill, and (3) no fill. The fill and no fill treatments were excavated to 30 cm depth as above. Fill treatments were filled with limestone pea gravel (diameter 0.6 cm, Fig. 4) until the sediment level was restored to original grade, while no fill treatments were left unfilled (Fig. 5). At each survey, short-shoot counts of seagrass species, Braun-Blanquet visual assessment of macroalgae and seagrass cover, depth, and video documentation were collected as above.

Data Analysis
Excavation Experiment
Thalassia testudinum and *Syringodium filiforme* short-shoot counts were square root transformed to meet assumptions of variance homogeneity and residual normality. Short-shoot count data from three survey dates, chosen to roughly coincide with one, two, and three years after deployment of the experiment (May 2001, August 2002, May 2003), were analyzed by species. One-way analysis of variance was conducted on each date’s data and a Bonferroni correction

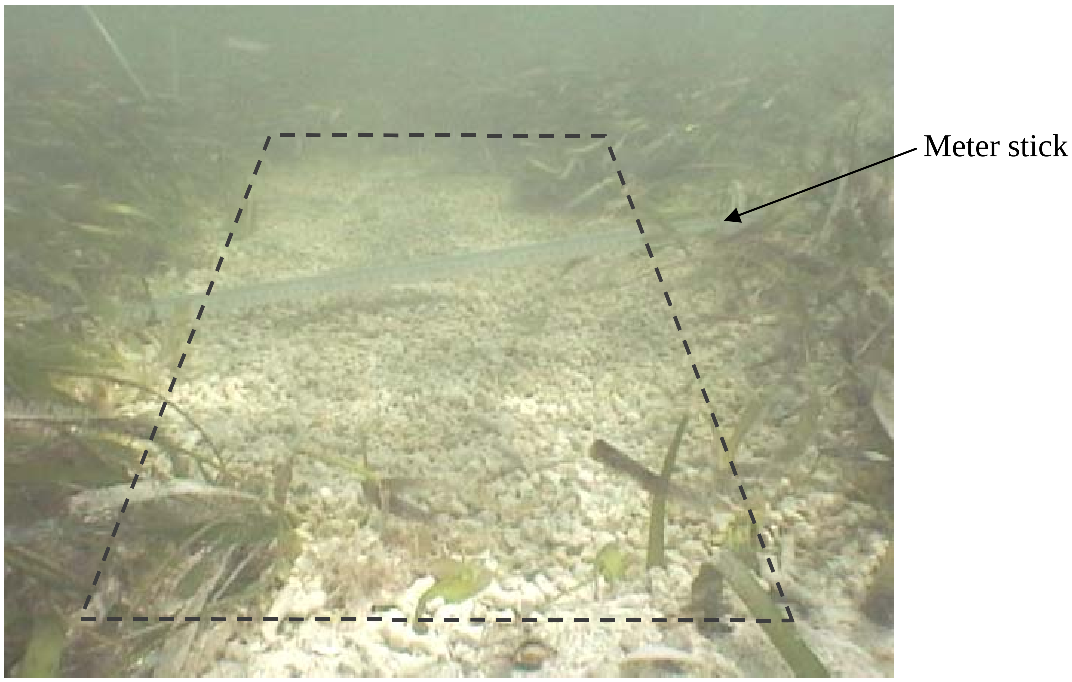


Figure 4. Fill treatment in September 2000, a few days after deployment. Pea gravel was added to restore the excavation to grade.

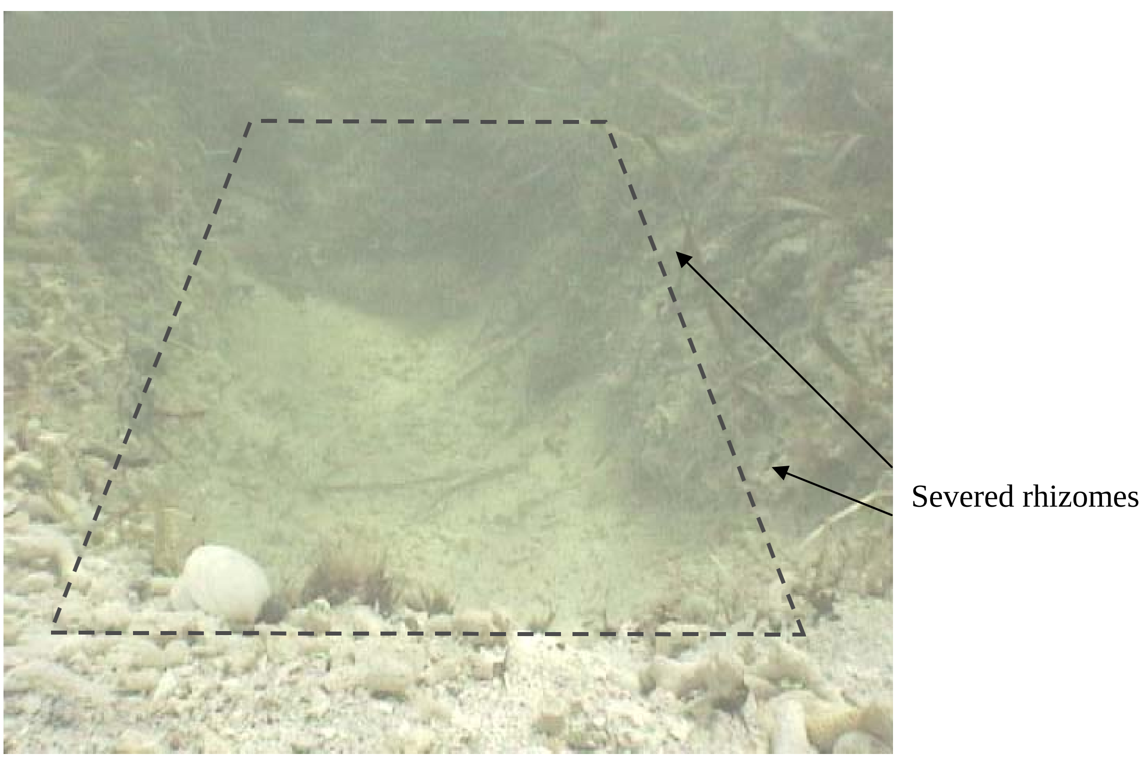


Figure 5. No Fill treatment in September 2000, a few hours after deployment.

was applied to the ANOVA F-test to account for repeated analyses (Underwood 1997). Tukey's studentized range test was used to conduct pair-wise comparisons among treatments when the overall ANOVA was significant at the $\alpha' = 0.017$ level ($\alpha = 0.05$ corrected for 3 ANOVAs).

Excavation experiment treatment depths were analyzed for two survey dates, May 2001 and August 2002. May 2001 data were natural-log transformed to meet assumptions of variance homogeneity and residual normality. While not all treatment residuals were distributed normally for August 2002 data, untransformed variances were homogeneous and transformation failed to resolve residual non-normality. One-way analysis of variance was conducted on transformed May 2001 data and untransformed August 2002 data. Tukey's studentized range test was used to conduct pair-wise comparisons among treatments when the overall ANOVA was significant at the $\alpha' = 0.025$ level (Bonferroni correction as above for 2 ANOVAs).

Fill Experiment

Syringodium filiforme short-shoot counts were square root transformed to meet assumptions of variance homogeneity and residual normality. Transformation was not necessary for *Thalassia testudinum* short-shoot counts. Short-shoot count data from three survey dates, chosen to roughly coincide with one, two, and three years after deployment of the experiment (May 2001, May 2002, May 2003), were analyzed by species. Analyses and corrections were applied as above.

No transformation was necessary for fill experiment treatment depths to meet assumptions of variance homogeneity and residual normality. Depths were analyzed for two survey dates, September 2001 and August 2002, roughly one and two years after deployment. Analyses and corrections were conducted as in the excavation experiment depth analyses.

Results

For both experiments the following system was used in the graphed results. Short-shoot data collected during all surveys is shown in a line and scatter plot, with arrows designating the survey dates that were selected for statistical analysis. Data in the line and scatter plots are displayed at the collection density of short shoots per 0.0625 m^2 quadrat. Data that were used in statistical analysis are plotted in bar graphs, presented in the form in which they were analyzed, including transformation if necessary. Equivalent short-shoot densities per square meter are given in the discussion of the results.

Excavation Experiment

Thalassia testudinum short-shoot counts for all the survey dates are shown in Figure 6. Short-shoot counts were significantly affected by treatment in May 2001 and August 2002 (Table 3). On both survey dates, there were no differences between the control and 10-cm treatment short-shoot counts, but both were significantly greater than the 20- and 40-cm treatments, which were not different from each other (Fig. 7). By May 2003, almost three years (1,077 days) after deployment of the experiment, there were no longer any significant differences in short-shoot counts among the four treatments (Table 3, Fig. 7). Although analyses were not conducted for all dates, it is apparent that the 10-cm treatments showed a rapid increase in short-shoot counts following initiation of the experiment, probably because the treatment involved minimal disturbance of belowground biomass, particularly to seagrass apical meristems. The 10-cm treatment resulted in removal of the aboveground short shoots, which quickly regenerated and

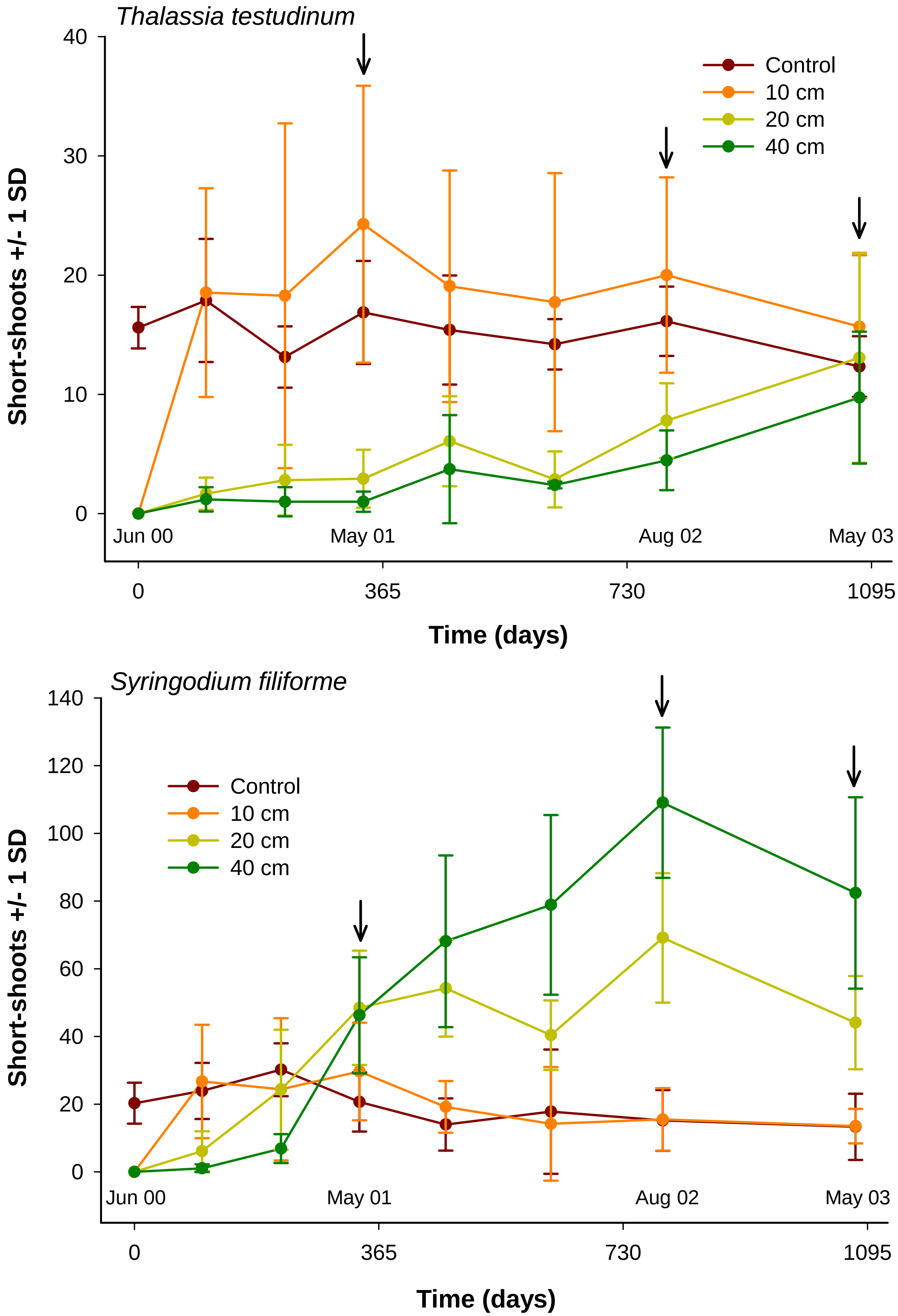


Figure 6. Excavation experiment short-shoot counts in 0.0625 m^2 quadrats for *Thalassia testudinum* and *Syringodium filiforme*. Survey dates used in statistical analysis are indicated by arrows. SD = standard deviation.

Table 3. Analysis of variance results for excavation experiment short-shoot counts. Tests significant at the $\alpha = 0.0167$ level are indicated by asterisks. SQRT TT and SQRT SF are square-root transformed *Thalassia testudinum* and *Syringodium filiforme* short-shoot counts, respectively, in 0.0625 m^2 quadrats.

Dependent Variable	Date	Independent Variable	SS	MS	F-value	P-value
	May 2001	treatment	54.52	18.17	27.58	< 0.0001 *
SQRT TT	August 2002	treatment	18.22	15.03	15.03	< 0.0001 *
	May 2003	treatment	1.92	0.64	1.01	0.4131
	May 2001	treatment	20.31	6.77	3.97	0.0273
SQRT SF	August 2002	treatment	167.50	55.83	36.79	< 0.0001 *
	May 2003	treatment	104.48	34.83	24.70	< 0.0001 *

were probably no different than control density in September 2000, 90 days after deployment (Fig. 6). Twenty- and 40-cm treatment short-shoot counts continued to be significantly lower than 10-cm and controls through August 2002, 780 days after deployment, although the short-shoot counts were greater than the same treatments in May 2001 (Fig. 7). Between 10 and 20 cm appears to be a critical depth beyond which damage to *T. testudinum* is such that recovery takes much longer. In May 2003, short-shoot densities ranged from 155.7 (standard deviation = 88.5) to 250.7 (SD = 95.9) short shoots m^{-2}, with an overall mean in control treatments for the survey periods of 242 short shoots m^{-2}.

Figure 6 shows the recovery pattern of *Syringodium filiforme* through time, with 10-cm treatments returning quickly to pre-injury conditions, while 20- and 40-cm treatments responded more slowly. *Syringodium filiforme* short-shoot counts responded differently to depth treatments than *Thalassia testudinum*. In May 2001, 11 months after deployment, *S. filiforme* short-shoot counts were not significantly different among treatments (Table 3, Fig. 7). In August 2002, 20- and 40-cm treatment short-shoot counts were not significantly different, but were significantly greater than counts in 10-cm and control treatments. By May 2003, while counts in the two deepest treatments had dropped, they were still significantly greater than 10-cm and control counts, and significantly different from each other (Fig. 7). Unlike *T. testudinum*, however, *S. filiforme* in the deepest treatments showed a compensatory recovery in which counts began to increase in the first year after deployment and were still significantly higher than controls almost three years (1,095 days) later (Fig. 6 and 7). By May 2003, short-shoot counts in 20- and 40-cm treatments had begun to decline, possibly in response to increasing *T. testudinum* short-shoot counts. Control *S. filiforme* short-shoot counts ranged from 213.3 (SD = 156.3) to 330.7 (SD = 140.4) m^{-2} during the study, with a mean of 262 short shoots m^{-2}. The maximum density was 1,745.1 (SD = 355.2) short shoots m^{-2} in the 40-cm treatment in August 2002.

Excavation treatment depths changed dramatically over time, with a roughly 50% decrease in depth in the three experimental treatments three months after deployment (Fig. 8). In May 2001, 330 days after deployment, treatment still significantly affected depth, although only the 40-cm treatment was different from the control and other depths (Table 4). In August 2002, 26 months (780 days) after deployment, the treatment depths were not significantly different (Table 4).

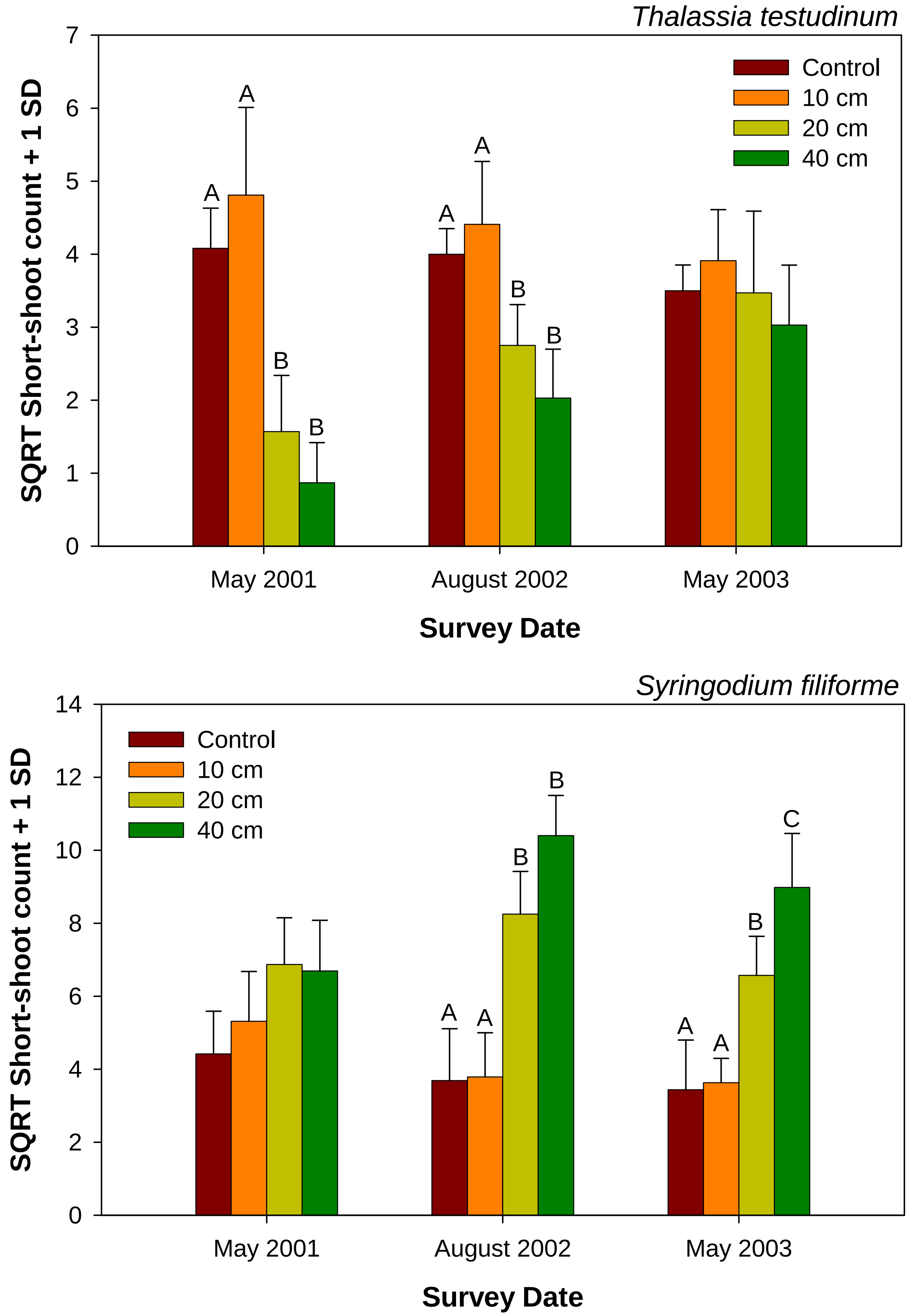


Figure 7. Excavation experiment square-root transformed short-shoot counts used in pair-wise comparisons. Letters indicate significant differences within a survey date. *Thalassia testudinum* counts were not significantly different in May 2003 and *Syringodium filiforme* counts were not significantly different in May 2001. SD = standard deviation.

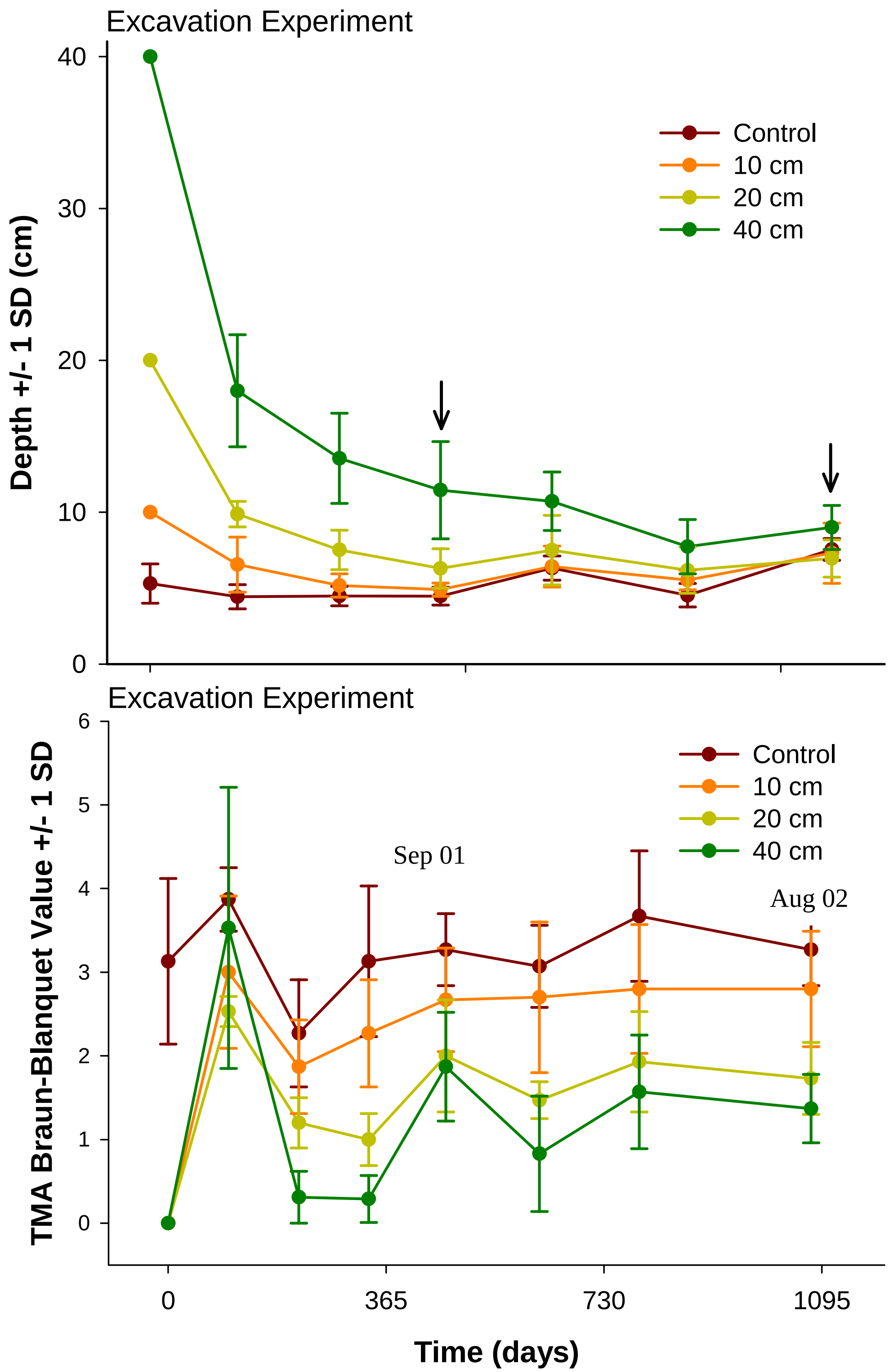


Figure 8. Excavation experiment depth and macroalgal cover. Depths used in statistical analysis are indicated by arrows. SD = standard deviation.

Table 4. Analysis of variance results for excavation experiment depths. Tests significant at the $\alpha = 0.025$ level are indicated by asterisks. May 2001 depths were natural-log transformed (LN depth) prior to analysis, while August 2002 depths were not.

Dependent Variable	Date	Independent Variable	SS	MS	F-value	P-value
LN depth	May 2001	treatment	2.49	0.83	17.77 `	< 0.0001 *
depth	August 2002	treatment	12.18	4.06	2.00	0.1540

Total macroalgal cover is presented for descriptive purposes only in the excavation experiment (Fig. 8). During creation of the 10-, 20-, and 40-cm treatments all macroalgae was removed. There was a very quick rebound in cover, with an increase from zero coverage in June 2000 to a range of 25-75% cover (Braun-Blanquet values > 2-4) 90 days later. Some of this cover was attributable to drift rather than attached macroalgae (Fig. 3). Then there was a decrease in cover for all treatments that coincided with a cold winter; temperatures on bank tops reached 10-11^{o}C. Although macroalgal cover increased after 330 days, it appears that there was a negative effect on macroalgae in the deeper treatments that persisted through May 2003 (1,077 days).

Fill Experiment

Thalassia testudinum short-shoot counts varied significantly among treatments in the fill experiment (Table 5, Fig. 9). As with the excavation experiment, *T. testudinum* fill and no fill short-shoot counts were significantly lower than control counts during the May 2001 and May 2002 surveys, 270 and 630 days after deployment (Fig. 10). By May 2003, there was no longer a significant difference in short-shoot count (Table 5, Fig. 10). Figure 9 shows a steady increase in *T. testudinum* short-shoot count in the two experimental treatments, and although not tested, the treatments appear to have recovered at the same rate, reaching control levels 990 days (33 months) after deployment. Control short-shoot counts ranged from 202.7 (SD = 88.4) to 262.2 (SD = 90.2) short shoots m^{-2} over the course of the experiment, with an overall mean of 234 short shoots m^{-2} in the control treatments. In fill and no fill treatments, short-shoot densities reached 24.0 and 28.4 (SD = 53.7 and 26.1) short shoots m^{-2} in May 2001 and 160.9 and 210.7 (SD = 59.5 and 80.2) short shoots m^{-2} by May 2003, respectively.

Syringodium filiforme short-shoot counts were also significantly affected by treatment (Table 5, Fig. 9). In May 2001, 270 days after deployment, there were no differences among treatments in short-shoot counts (Table 5, Fig. 9). By May 2002, 630 days after the experiment was initiated, all treatments were significantly different from one another, with the no fill treatment having the highest short-shoot counts and the control treatment having the lowest short-shoot counts (Fig. 10). This condition continued through May 2003, with treatments remaining significantly different from each other 990 days after deployment (Fig. 9). Figure 9 shows that *S. filiforme* in the no fill treatment demonstrated the same compensatory recovery that was exhibited in the 20- and 40-cm treatments in the excavation experiment. Short-shoot counts of *S. filiforme* in the fill treatment also showed an increase over time, but not as dramatic an increase as that of the no fill treatments (Fig. 9 and 10). Interestingly, *S. filiforme* short-shoot counts in control treatments of the fill experiment were lower than control treatments of the excavation experiment. Densities in the fill experiment controls ranged from 96.0 to 148.4 (SD = 102.8 and 99.3) short shoots m^{-2}, with a mean of 117 short shoots m^{-2}. No fill densities peaked at 1,162.7 (SD = 420.5) short shoots m^{-2}, about 10 times higher than control densities, in May 2002. Fill treatment densities also peaked in May 2002, with 493.3 (SD = 233.5) short shoots m^{-2}.

Table 5. Analysis of variance results for fill experiment short-shoot counts. Tests significant at the α = 0.0167 level are indicated by asterisks. TT and SQRT SF are *Thalassia testudinum* and square-root transformed *Syringodium filiforme* short-shoot counts, respectively, in 0.0625 m^2 quadrats.

Dependent Variable	Date	Independent Variable	SS	MS	F-value	P-value
	May 2001	treatment	429.45	214.72	15.69	0.0003 *
TT	May 2002	treatment	414.90	207.45	11.24	0.0010 *
	May 2003	treatment	67.75	33.88	1.60	0.2344
	May 2001	treatment	7.02	3.51	2.94	0.0861
SQRT SF	May 2002	treatment	90.66	45.33	26.32	< 0.0001 *
	May 2003	treatment	120.97	60.49	22.15	< 0.0001 *

The depth of no fill treatments in the fill experiment changed markedly in the first 120 days following deployment in September 2000, declining from a mean depth of 27.6 cm to 12.2 cm. At no time did the fill treatment depths differ from controls (Table 6, Fig. 11), which demonstrate that the fill material was not eroded away by water flow. In fact, by August 2002, 690 days after deployment, there were no significant differences in depth among any treatments (Table 6). As with the 20- and 40-cm treatments in the excavation experiment, some time during the second year following deployment the no fill treatment filled in because the margins collapsed into injuries and suspended sediments settled into them.

Total macroalgal cover was variable in all treatments of the fill experiment (Fig. 11). Over time there was a moderate increase in macroalgal cover, from values much less than 5% (Braun-Blanquet value $\leq$ 1) to values greater than 25% (Braun-Blanquet value $\geq$ 2). As in the excavation experiment, although no analyses were conducted, it appears that macroalgal cover in the no fill treatment continued to be lower than cover in controls through the last survey date 33 months after deployment. Dips in cover in controls correspond to the January sampling dates, suggesting that macroalgal cover is influenced by some seasonal factor, such as water temperature or light (Fig. 11).

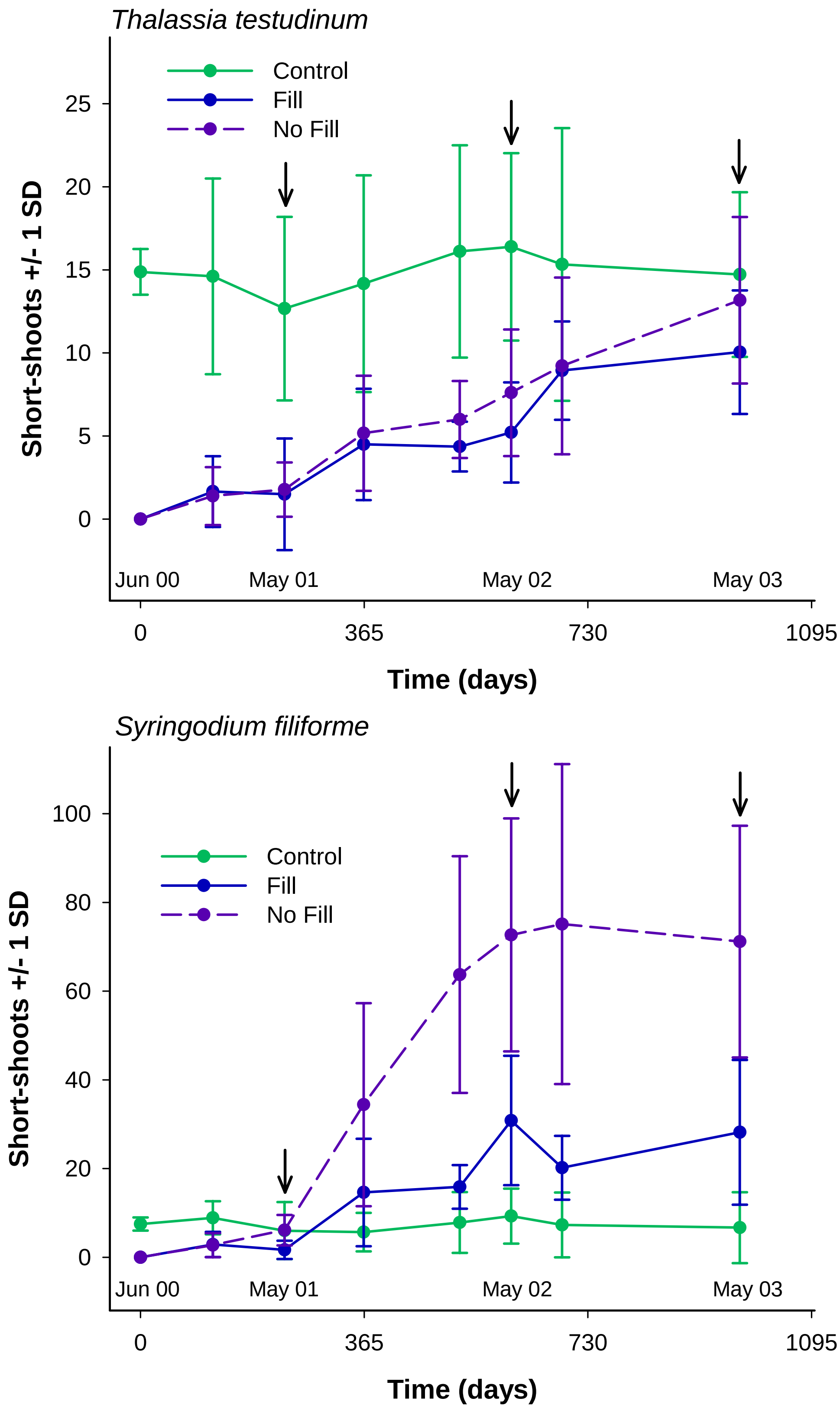
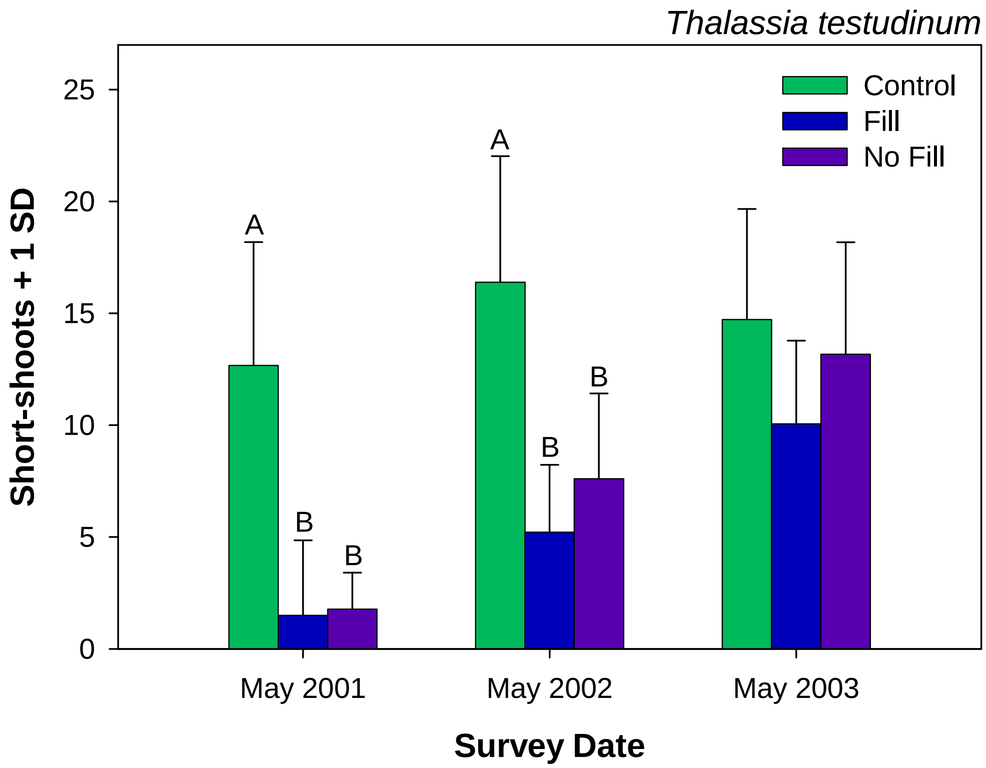


Figure 9. Fill experiment short-shoot counts in 0.0625 m^2 quadrats for *Thalassia testudinum* and *Syringodium filiforme*. Survey dates used in statistical analysis are indicated by arrows. SD = standard deviation.



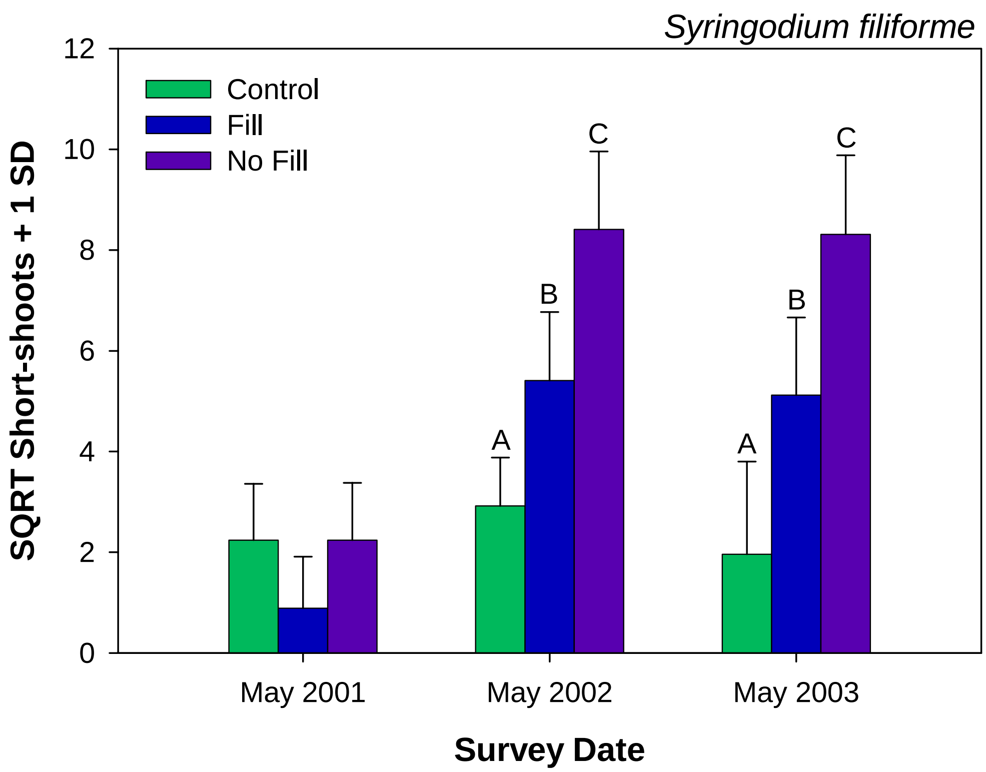


Figure 10. Fill experiment short-shoot counts used in pairwise comparisons. Letters indicate significant differences within a survey date. Thalassia testudinum counts were not significantly different in May 2003 and square-root transformed Syringodium filiforme counts were not significantly different in May 2001. SD = standard deviation.

Table 6. Analysis of variance results for fill experiment depths. Tests significant at the α = 0.025 level are indicated by asterisks.

Dependent Variable	Date	Independent Variable	SS	MS	F-value	P-value
depth	May 2001	treatment	33.47	16.73	9.92	0.0018*
depth	May 2002	treatment	7.19	3.60	1.92	0.1815

Discussion

Results of the excavation and fill experiments demonstrated that injuries to seagrass banks that exceeded 10 cm in depth had significant impacts on short-shoot counts of *Thalassia testudinum* and *Syringodium filiforme*, and in some treatments those impacts persisted three years after initiation. In both experiments, *T. testudinum* short-shoot density in all treatments returned to control levels between the second and third year following injury. *Syringodium filiforme* short-shoot densities, however, remained elevated in most deep (> 20 cm) treatments through the May 2003 survey (Fig. 12). Total macroalgal cover also tended to be lower in more disturbed treatments. Although *T. testudinum* short-shoot densities and treatment depths had returned to pre-injury levels in roughly two to three years, treatments continued to impact *S. filiforme* short-shoot counts and macroalgal cover.

The response of *Thalassia testudinum* to these treatments may be explained in part by its morphological characteristics. As much as 80 to 90% of the dry weight of *T. testudinum* is belowground biomass (van Tussenbroek 1998; Kaldy and Dunton 2000), and the belowground fraction may extend deeper than 1 m into the sediment (Marba et al. 1993). Shallow injuries (≤ 10 cm) probably disturb very little of the belowground biomass and apical meristems. Experimental plots may recover quickly because of regrowth of intact short shoots, which were "shaved" by the treatment while no rhizomes were severed. Deeper injuries, however, disturb more of the belowground biomass, thereby severing rhizomes, damaging apical meristems, and removing the root-rhizome-sediment matrix that underlies the visible meadow. Regrowth into deeper injuries (≥ 20 cm) can be slow because it requires vegetative growth from the injury margins and/or recruitment of seedlings, processes dependent on low densities of horizontal meristems and seedlings (van Tussenbroek et al. 2000; Whitfield et al. in press) and the slow rate of clonal growth of *T. testudinum*. Additionally, the excavation of sediment may expose *T. testudinum* apical meristems to light, and there is some evidence to suggest that light inhibits meristematic tissue growth (Terrados 1997). Finally, there appeared to be no significant effect of fill material on the growth of *T. testudinum* into the experimental plots, as demonstrated by the responses in the fill and no fill treatments (Fig. 9).

The response of *Syringodium filiforme* to experimental manipulation was quite different than the response of *Thalassia testudinum*. Once all seagrass above- and belowground biomass was removed, the fast growth of *S. filiforme* conferred a short-term competitive advantage, and *S. filiforme* short-shoot densities quickly exceeded those of the surrounding, undisturbed seagrass bed. In some cases a 10-fold increase in short-shoot density of *S. filiforme* occurred in the deeper, unfilled treatments (≥ 20 cm) (Fig. 13). Williams (1987) reported a doubling of *S. filiforme* short-shoot density after clipping the aboveground biomass of *T. testudinum* in a mixed species seagrass bed in the Caribbean. In our study, an even greater increase in short-shoot

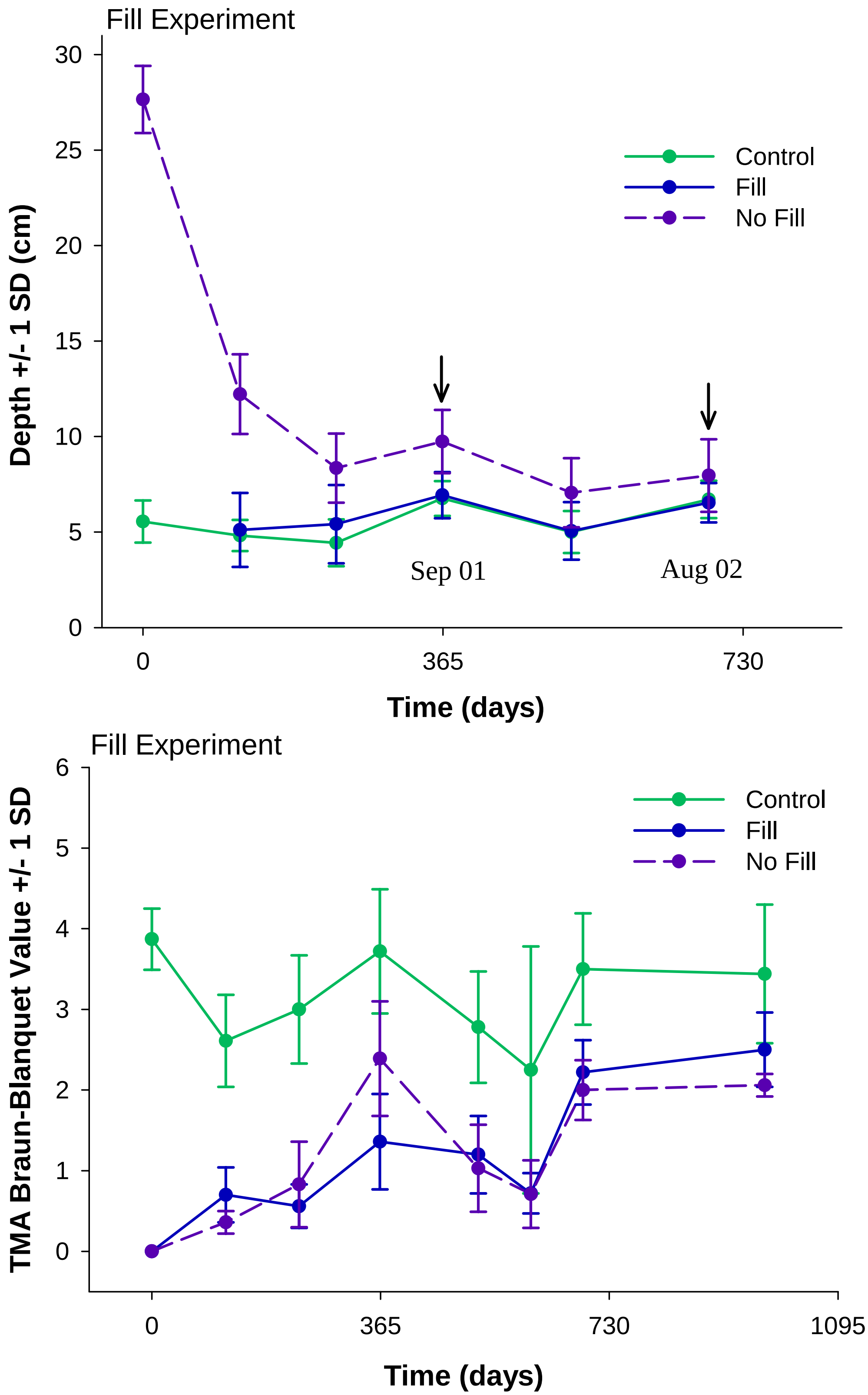


Figure 11. Fill experiment depth and macroalgal cover. Depths used in statistical analysis are indicated by arrows. SD = standard deviation.

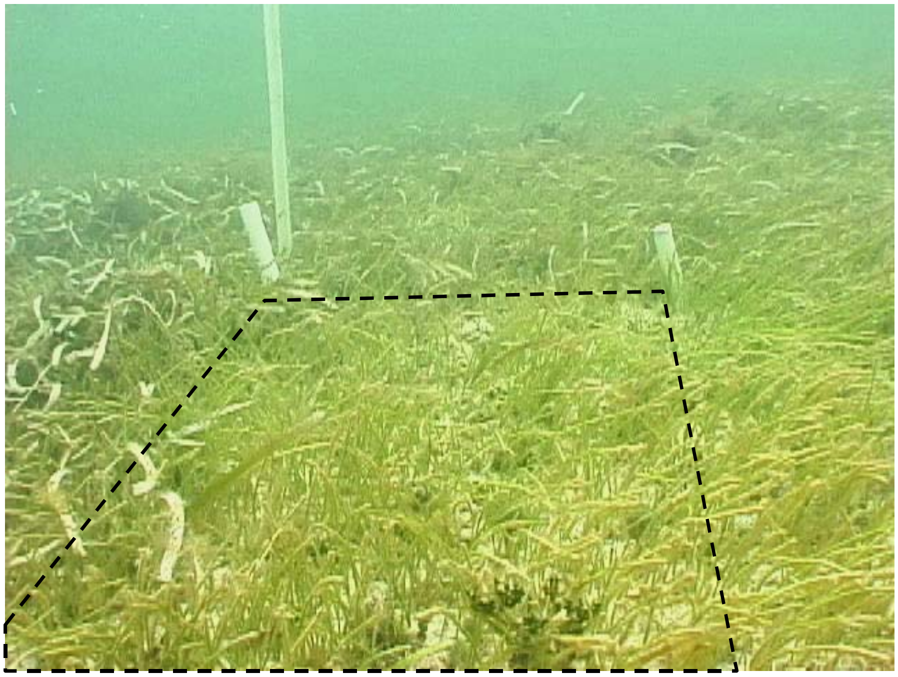


Figure 12. A 40-cm excavation treatment in August 2002, 780 days after deployment. The dominant seagrass inside the treatment is *Syringodium filiforme*. The injury increased in size to include the area to the right of the dotted line, where more *S. filiforme* is present.

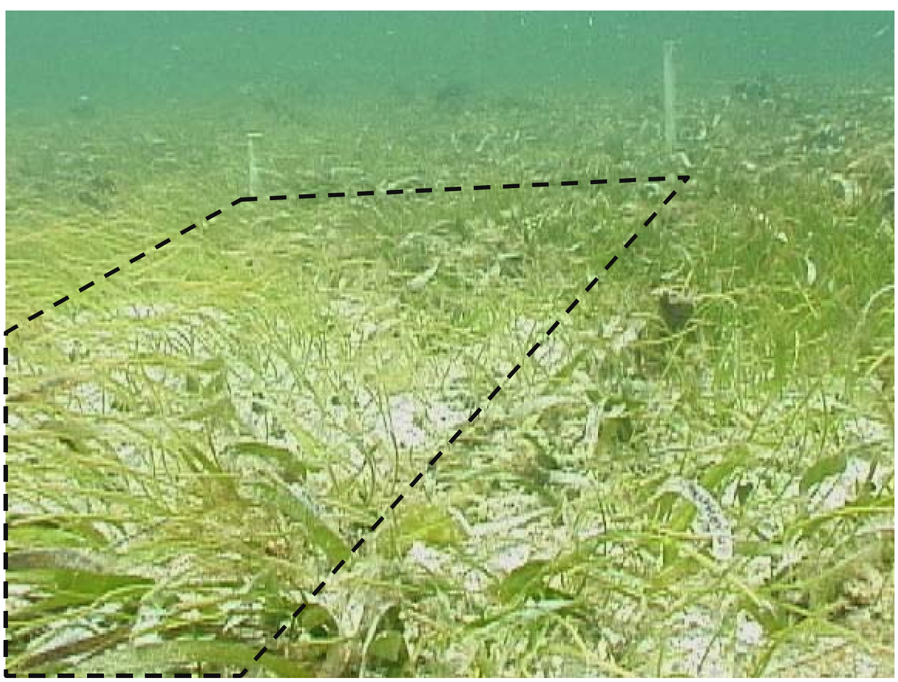


Figure 13. No fill treatment in August 2002, 690 days after deployment. The dominant seagrass inside the treatment is *Syringodium filiforme*.

density was probably a result of not only increased light from above, but decreased competition for space in the substrate (Williams 1988; Duarte et al. 1998, Duarte et al. 2000). During the second year of the study we started to see a leveling off or decrease of *S. filiforme* short-shoot density, and we predict that as *T. testudinum* becomes more established in the deeper experimental plots, *S. filiforme* will decline further (Williams 1988; Williams 1990; Kenworthy et al. 2002).

The results from the fill treatment suggest that pea gravel may have physically inhibited *Syringodium filiforme* recovery along the injury margins. Fill treatment *S. filiforme* short-shoot densities nine months after initiation of the experiment were about 25% of the densities in the control and no fill treatments (26.7 versus 96.0 short shoots m^{-2}). One year later, in May 2002, *S. filiforme* fill treatment short-shoot counts had reached levels about 3.5-times higher than controls, but were still less than half that of no fill plots (Fig. 6). The only difference between the fill and no fill treatments was the presence of pea gravel and probably the much greater proportion of fine sediment that accumulated in no fill plots (Fig. 11). Also, there may have been less organic matter, and therefore less nutrient availability in the pea gravel.

Results of the excavation and fill experiments have implications for seagrass restoration. Without intervention, our experimental treatment *Thalassia testudinum* short-shoot counts reached control levels in 33 to 36 months. This recovery estimate agrees with previous studies on *T. testudinum* recovery in narrow propeller scars. Zieman (1976) reported recovery times of 2-5 years in southern Florida and the Florida Keys, while Dawes et al. (1997) predicted recovery in 2-7 years in Tampa Bay *T. testudinum* beds. A third study found recovery rates of 7-10 years in the Florida Keys (Kenworthy et al. 2002). In these studies, recovery was defined as scar disappearance or recovery was predicted from a regression of short-shoot density change over time. Our results demonstrate that injury effects such as increased *Syringodium filiforme* short-shoot counts and decreased macroalgal cover may persist even though *T. testudinum* short-shoot counts have reached ambient densities. Thus, how recovery is defined is very important.

One factor that was not addressed in this study is the vulnerability of injuries to further erosion. There were no major storms during the three years after deployment of these experiments, but we know from previous studies that storms can have dramatic and lasting impacts on seagrass beds (Preen et al. 1995), especially when there is existing motor vessel damage (Whitfield et al. 2002). Although not tested, we predict that filling of injuries would leave them less susceptible to storm-induced erosion. In the fill experiment, depths of fill treatments were not significantly different than controls one and two years after deployment of the fill material. This fact demonstrates that there was very little erosion of fill material from injuries. Had a storm occurred, unfilled treatments from both experiments would probably have experienced erosion, especially if the storm occurred early in the recovery process. Sedimentation into unfilled treatments begins with the collapse of injury margins into the injury itself and continues with deposition of sediment trapped by seagrass in surrounding beds. Until a new root-rhizome-sediment matrix is established by the regrowth of seagrass into the unvegetated area, the unconsolidated sediment is susceptible to erosion (Zieman 1976; Sargent et al. 1995; Whitfield et al. 2002). Filling of injuries with pea gravel provides protection from erosion, does not inhibit growth of *Thalassia testudinum*, and might minimize stress of competition from *Syringodium filiforme*. The placement of fill into larger blowhole injuries that take decades to recover

(Fonseca et al. 2002) should diminish the probability of further erosion and enhance recovery by allowing regrowth of seagrasses.

Acknowledgments
We would like to thank Craig Bonn, Kari Ferenc, Kevin Kirsch, Sean Meehan, Art Schwarzchild, Charles Jabaly, Sean Meehan, Kevin Kirsch, and Amy Uhrin for assistance with field work. Arthur Schwarzschild provided the data on grain size for the sediment tube fill material. The views expressed in this report do not necessarily reflect the views of NOAA.

References

Bell, S.S., R.A. Brooks, B.D. Robbins, M.S. Fonseca, and M.O. Hall. 2001. Faunal response to fragmentation in seagrass habitats: implications for seagrass conservation. Biological Conservation 100: 115-123.

Creed, J.C., and G.M.A. Filho. 1999. Disturbance and recovery of the macroflora of a seagrass (*Halodule wrightii* Ascherson) meadow in the Abrolhos Marine National Park, Brazil: an experimental evaluation of anchor damage. Journal of Experimental Marine Biology and Ecology 235: 285-306.

Dawes, C.J., J. Andorfer, C. Rose, C. Uranowski, and N. Ehringer. 1997. Regrowth of *Thalassia testudinum* into propeller scars. Aquatic Botany 59: 139-155.

Duarte, C.M., J. Terrados, N.S.R. Agawin, M.D. Fortes, S. Bach, and W.J. Kenworthy. 1997. Response of a mixed Philippine seagrass meadow to experimental burial. Marine Ecology Progress Series 147: 285-294.

Duarte, C.M., M. Merino, N.S.R. Agawin, J. Uri, M.D. Fortes, M.E. Gallegos, N. Marba, and M.A. Hemminga. 1998. Root production and belowground seagrass biomass. Marine Ecology Progress Series 171: 97-108.

Duarte, C.M., J. Terrados, N.S.R. Agawin, and M.D. Fortes. 2000. An experimental test of the occurrence of competitive interactions among SE Asian seagrasses. Marine Ecology Progress Series 197: 231-240.

Dunton, K.H., and S.V. Schonberg. 2002. Assessment of propeller scarring in seagrass beds of the south Texas coast. Journal of Coastal Research 37: 100-110.

Durako, M.J., M.O. Hall, F. Sargent, and S. Peck. 1992. Propeller scars in seagrass beds: an assessment and experimental study of recolonization in Weedon Island State Preserve, Florida. *In*: Webb, F.J., Jr. (ed). Proceedings of the Nineteenth Annual Conference on Wetlands Restoration and Creation. Tampa: Hillsborough Community College, pp. 42-53.

Fonseca, M.S., P.E. Whitfield, W.J. Kenworthy, D.R. Colby, and B.E. Julius. 2002. Use of two spatially explicit models to determine the effect of injury geometry on natural resource recovery. Aquatic Conservation: Marine and Freshwater Ecosystems.

Fourqurean, J.W., A. Willsie, C.D. Rose, and L.M. Rutten. 2001. Spatial and temporal pattern in seagrass community composition and productivity in South Florida. Marine Biology 138: 341-354.

Fourqurean, J.W., G.V.N. Powell, W.J. Kenworthy, and J.C. Zieman. 1995. The effects of long-term manipulation of nutrient supply on competition between the seagrasses *Thalassia testudinum* and *Halodule wrightii* in Florida Bay. Oikos 72: 349-358.

Hastings, K., P. Hesp, and G.A. Kendrick. 1995. Seagrass loss associated with boat moorings at Rottnest Island, Western Australia. Ocean and Coastal Management 26: 225-246.

Kaldy, J.E., and K.H. Dunton. 2000. Above- and below-ground production, biomass and reproductive ecology of *Thalassia testudinum* (turtle grass) in a subtropical coastal lagoon. Marine Ecology Progress Series 193: 271-283.

Kenworthy, W.J., M.S. Fonseca, P.E. Whitfield, K.K. Hammerstrom, and A.C. Schwarzschild. 2000. A comparison of two methods for enhancing the recovery of seagrasses into propeller scars: mechanical injection of a nutrient and growth hormone solution vs. defecation by roosting seabirds. Final report to the Florida Keys Restoration Trust Fund, Tavernier, Florida, September 2000. 40 pp.

Kenworthy, W.J., M.S. Fonseca, P.E. Whitfield, and K.K. Hammerstrom. 2002. Analysis of seagrass recovery in experimental excavations and propeller-scar disturbances in the Florida Keys National Marine Sanctuary. Journal of Coastal Research 37: 75-85.

Marba, N., M.E. Gallegos, M. Merino, and C.M. Duarte. 1993. Vertical growth of *Thalassia testudinum*: seasonal and interannual variability. Aquatic Botany 47: 1-12.

Powell, G.V.N., J.W. Fourqurean, W.J. Kenworthy, and J.C. Zieman. 1991. Bird colonies cause seagrass enrichment in a subtropical estuary: observational and experimental evidence. Estuarine, Coastal and Shelf Science 32: 567-579.

Powell, G.V.N., W.J. Kenworthy, and J.W. Fourqurean. 1989. Experimental evidence for nutrient limitation of seagrass growth in a tropical estuary with restricted circulation. Bulletin of Marine Science 44: 324-340.

Preen, A.R., W.J. Lee Long, and R.G. Coles. 1995. Flood and cyclone related loss, and partial recovery, of more than 1000 km^2 of seagrass in Hervey Bay, Queensland, Australia. Aquatic Botany 52: 3-17.

Sargent, F.J., T.J. Leary, S.W. Crewz, and C.R. Kruer. 1995. Scarring of Florida's seagrasses: assessment and management. Florida Marine Research Institute Technical Report TR-1, Florida Marine Research Institute, St. Petersburg, FL, 37 pp.

Short, F.T., and S. Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. Environmental Conservation 23: 17-27.

Smith, N.P. 1994. Long-term Gulf-to-Atlantic transport through tidal channels in the Florida Keys. Bulletin of Marine Science 54: 602-609.

Terrados, J. 1997. Is light involved in the vertical growth response of seagrasses when buried by sand? Marine Ecology Progress Series 152: 295-299.

Underwood, A.J. 1997. Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge University Press, Cambridge, UK. 504 pp.

Uhrin, A.V., and J.G. Holmquist. 2003. Effects of propeller scarring on macrofaunal use of the seagrass *Thalassia testudinum*. Marine Ecology Progress Series 250: 61-70.

van Tussenbroek, B.I. 1998. Above- and below-ground biomass and production by *Thalassia testudinum* in a tropical reef lagoon. Aquatic Botany 61: 69-82.

van Tussenbroek, B.I., C.A. Galindo, and J. Marquez. 2000. Dormancy and foliar density regulation in *Thalassia testudinum*. Aquatic Botany 68: 281-295.

Walker, D.I., R.J. Lukatelich, G. Bastyan, and A.J. McComb. 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. Aquatic Botany 36: 69-77.

Whitfield, P.E., W.J. Kenworthy, M.J. Durako, K.K. Hammerstrom, and M.F. Merello. 2002. Recruitment of *Thalassia testudinum* seedlings into physically disturbed seagrass beds. Marine Ecology Progress Series.

Williams, S.L. 1987. Competition between the seagrasses *Thalassia testudinum* and *Syringodium filiforme* in a Caribbean lagoon. Marine Ecology Progress Series 35: 91-98.

Williams, S.L. 1990. Experimental studies of Caribbean seagrass bed development. Ecological Monographs 60: 449-469.

Zieman, J.C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. Aquatic Botany 2: 127-139.

Biogeographic Analysis of Tortugas Ecological Reserve: Examining the Refuge Effect Following Reserve Designation

John S. Burke, Michael L. Burton, Carolyn A. Currin, Donald W. Field, Mark S. Fonseca, Jonathan A. Hare, W. Judson Kenworthy, and Amy V. Uhrin (NOAA/NOS/NCCOS Center for Coastal Fisheries and Habitat Research, Beaufort, NC)

Project Goals

The ultimate goal of this program is to provide a measurement of the refuge effect of the Tortugas Ecological Reserve (TER). To achieve such an assessment, we have focused our efforts on: 1) an extensive habitat characterization of the benthos in and around TER, 2) a multiple stable isotope analysis of the food web supporting fish production in TER, 3) an examination of the abundance and composition of reef fishes in TER, and 4) an examination of the effects of trawl exclusion on benthic habitats located in TER. Since 2000, a total of eight cruises, utilizing three different NOAA ships, have been conducted in support of this research (Table 1).

The need for detailed habitat characterization is inextricably linked with the question of where to establish a reserve. Biogeography simply focuses attention on what ecologists have implicitly known for many years, that the geographic context of the biota not only signals the organization of ecosystem processes, but in many instances acts to control or strongly modify those processes. In other words, to examine living organisms without regard to their spatial and temporal organization at multiple scales of organization, and in association with first order environmental factors will fail to elucidate vulnerability, susceptibility, and resilience of the ecosystem. Many reef fishes leave the structure of the reef at night to forage in adjacent sand, algal, and seagrass flats, thereby importing significant amounts of nutrients onto the reef environment, contributing to its high productivity (Meyer et al. 1983). This mass transfer also ultimately contributes to energy requirements of small grazers that cannot access the adjacent, non-coral reef resources. The importance of off-reef migration should be reflected in food web analyses. Multiple stable isotope analysis has been used to trace the sources of primary production contributing to the food web in a variety of marine environments (Fry et al. 1982; Peterson et al. 1985). In addition, stable isotopes can be used to track animal movements between habitats (Fry et al. 1999).

Methods

We chose to adopt a sampling protocol that focused on habitat interfaces (i.e., areas where coral reef meets seagrass/algal plain), using randomly selected, permanent transects. The area within and outside the Reserve was divided into three strata: 1) the existing Dry Tortugas National Park (DTNP, Park), 2) the Reserve (not falling within the existing jurisdiction of the DTNP), and 3) a 5 km buffer around the Reserve not within the DTNP (Out) for before/after comparisons (a Before-After Control Impact (BACI) sampling strategy (Underwood 1991). Lines were drawn through the longest axis of the Tortugas Bank and DTNP, normal to the prevailing northwest-southeast currents and bisecting these features into areas facing either upstream (North) or downstream (South; Fig. 1). In conjunction with the Reserve, Park, and Out strata, the interface zones along both of the large reef structures in Tortugas North (Tortugas Bank and DTNP) were designated as one of six categories: 1) Out North; 2) Out South; 3) Park North; 4) Park South; 5) Reserve North; and 6) Reserve South.

Table 1. Completed research cruises.

Cruise Name	Dates	Vessel	Sea Days	# Dives
FE-00-09-BL	7/10/00 - 8/4/00	NOAA Ship *FERREL*	20	164
OT-01-01	1/4/01 - 2/13/01	NOAA Ship *OREGON II*	8	0
FE-01-07-BL	4/8/01 - 4/20/01	NOAA Ship *FERREL*	12	55
FE-01-10-BL	6/17/01 - 7/1/01	NOAA Ship *FERREL*	13	111
FE-01-11-BL	7/8/01 - 7/21/01	NOAA Ship *FERREL*	13	86
GU-01-03	7/2/01- 7/3/01	NOAA Ship *GORDON GUNTER*	2	0
	5/11/02 - 5/13/02	*F/V Alexis M* (charter)	3	1
	5/27/02 - 5/30/02	*F/V Alexis M* (charter)	4	12
	6/6/02 - 6/12/02	*F/V Alexis M* (charter)	4	9
	6/23/02- 6/26/02	*F/V Alexis M* (charter)	4	10
FE-02-14-BL	6/17/02 - 7/12/02	NOAA Ship *FERREL*	24	184
FE-02-15-FK	7/15/02 - 7/19/02	NOAA Ship *FERREL*	5	49
	7/23/02 - 7/26/02	*F/V Alexis M* (charter)	4	13
	10/20/02 - 10/23/02	*F/V Alexis M* (charter)	4	8
TOTAL DAYS AT SEA			120	
TOTAL # DIVES				702

To choose five random transects from within each of the six categories, we used ESRI's ArcInfo® software and imposed a line at roughly the 10 fathom isobath around the perimeter of the two large coral features because this roughly approximated the location of the sand-coral interface. Each line was then broken down into the six categories and random distances, 50 m apart along each line type, were selected. It was estimated that 50 m would allow for visual isolation of potentially adjacent sites, an important factor for our fish visual census method. The selection of random locations along line type was continuous across the entire landscape, even though line types were segmented among the two large coral features, yielding true randomization. Random points were spaced 50 m along segments so that visual census methods would not overlap in the event two random numbers were adjacent to each other (which did not occur).

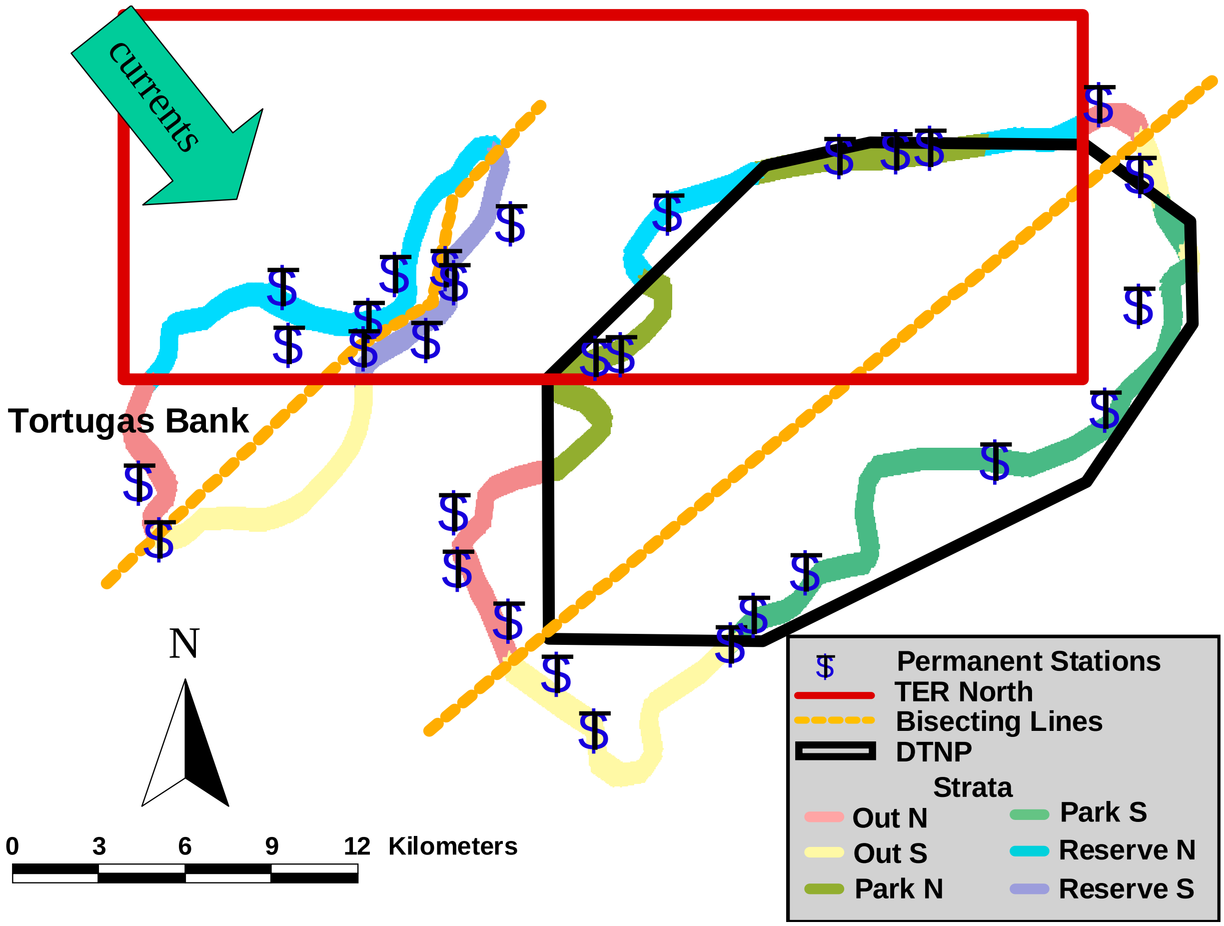


Figure 1. Location of interface strata and 30 permanent stations.

Habitat Characterization

Coarse-scale mapping of each station has been conducted using a variety of platforms over the years to address issues of scale. A MiniBAT® tow body housing a downward facing SeaViewer® color Sea-Drop camera was used to videotape the seafloor at ~ 10 cm resolution. Video was recorded onto either digital, SVHS, or VHS tapes and the exact time and location along each transect was stamped onto the video using the Horita® GPT-50 GPS video titler linked to a Trimble GPS Pathfinder Pro XR/XRS. Track lines were recorded using Trimble ASPEN® software. Beginning in 2002, we began mapping the stations using a sidescan sonar (Sport Scan®). On several occasions, the MiniBAT was run simultaneously with the Sport Scan as a means of video-calibrating the sonar images. A RoxAnn® Groundmaster seabed classification system was deployed and run simultaneously with the MiniBAT unit on occasion as well.

Fine-scale mapping by divers has taken place since 2001. Semi-permanent rebar stakes were established at the interface of each station by divers. Dive teams followed transect lines beginning from the permanent/temporary marker at the interface and running 30 m out in either direction, perpendicular to the interface (sand plain vs reef). A digital video camera (SONY DCR TRV900 MiniDV Handycam® camcorder) contained in an underwater housing, was used to record the substrate along the length of each transect at 40 cm above the substrate.

Food Web Analysis
We collected samples for use in a multiple stable isotope analysis of the food web supporting fish production in TER. Samples collected from within the permanent stations included primary producers (phytoplankton, benthic microalgae, benthic macroalgae, and seagrass) and secondary consumers (fish, crabs, and shrimp). Several methods of collection were employed including hook and line from the research vessel, divers armed with sling spears, beam trawls, hand collection by divers, and bucket/Niskin Bottle casts. This sampling targeted specific species from different levels of the food web in order to examine trophic relationships in the reef-interface zone.

Reef Fish
Paired band transect visual censuses were made by divers over the reef and soft bottom habitat along the 30 m transects as described above. Fish counts were made within 1 m on either side of the permanent transect.

Trawl Impact
Along the northern boundary of Tortugas North, pairs of randomly selected coordinates were chosen for beam trawl samples. The coordinates served as starting points for trawl tow paths. One coordinate of each pair was located ~ 2 km due south of the Tortugas North northern boundary (within the Reserve), and the other ~ 2 km due north of the boundary (outside the Reserve). One set of coordinates spanned the eastern boundary of Tortugas North. In this case, one coordinate was located ~ 2 km due west of Tortugas North's eastern boundary (within the Reserve), and the other ~ 2 km due east of the boundary (outside the Reserve). We conducted three-minute tows at each coordinate using a modified 2 m beam trawl with a 3 mm mesh cod end.

Results to Date
Habitat Characterization
Track line files generated in ASPEN were exported to Microsoft® Excel. The times and coordinates displayed on the videos correspond to the chronologic records in the ASPEN-generated Excel spreadsheet. While the video was playing, CCFHR staff recorded a habitat code every five seconds based upon what was viewed in the video frame at that time. The track line spreadsheet, complete with habitat classification, was converted to a text file and imported into ESRI's ArcView® software. In ArcView, the habitat codes were assigned unique color values. The color-coded track lines were then displayed on a chart of the Dry Tortugas, effectively creating a habitat map of the area. SportScan images will be calibrated with associated video transects as well. Analysis is on-going at CCFHR.

Food Web Analysis
The majority of fish analyzed so far exhibit a C isotope signature of -16 or less, consistent with a food web based on benthic primary producers (Fig. 2). Penaeid shrimp (Penaeidae), flounder

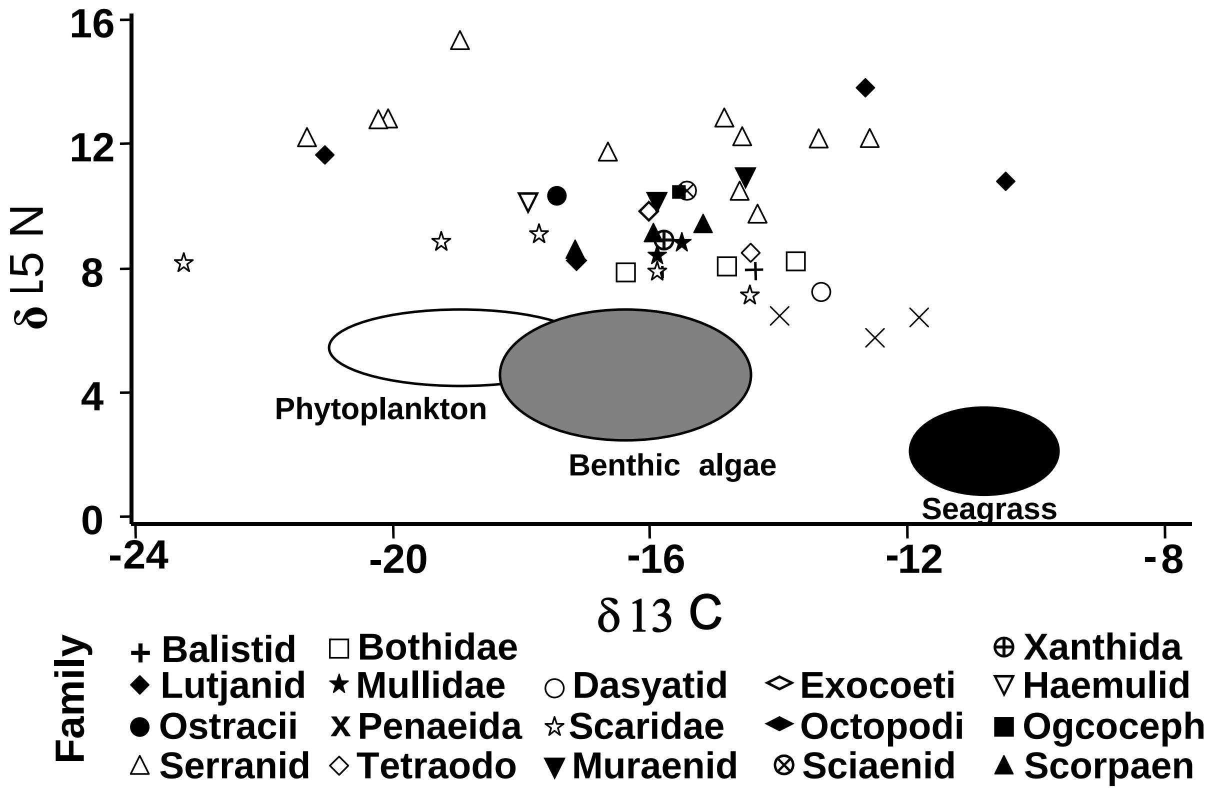


Figure 2. Carbon isotopic signatures for various fish families found in TER.

(Bothidae) and gray snapper (Lutjanidae) samples exhibited the most enriched C values, consistent with a food web based in part on seagrass carbon. Some fish, such as red grouper (family Serranidae) and parrotfish (Scaridae) exhibited a wide range in C isotope values. Additional results will help us to determine whether there is a significant geographic or reserve effect on the food webs utilized by these fish.

Nitrogen isotope values are helpful in determining ontogenetic changes in fish diets, and particularly in detecting increases in trophic level. This is because animals preferentially retain ^{15}N, so that there is an approximate 3 per mil increase in d^{15}N per trophic level. This approach can be used to help determine whether ontogenetic diet changes include a switch from herbivory to carnivory (Cocheret de la Morineire et al. 2003). Figure 3 shows an increase in nearly two trophic levels as red grouper (Serranidae) increase in size from 25 to 70 cm. Parrotfish (Scaridae), however, exhibit little trophic change between 8 and 25 cm length (Fig. 3). These data can help to predict the potential ecosystem effects of changes in average fish size as the result of no-take regulations.

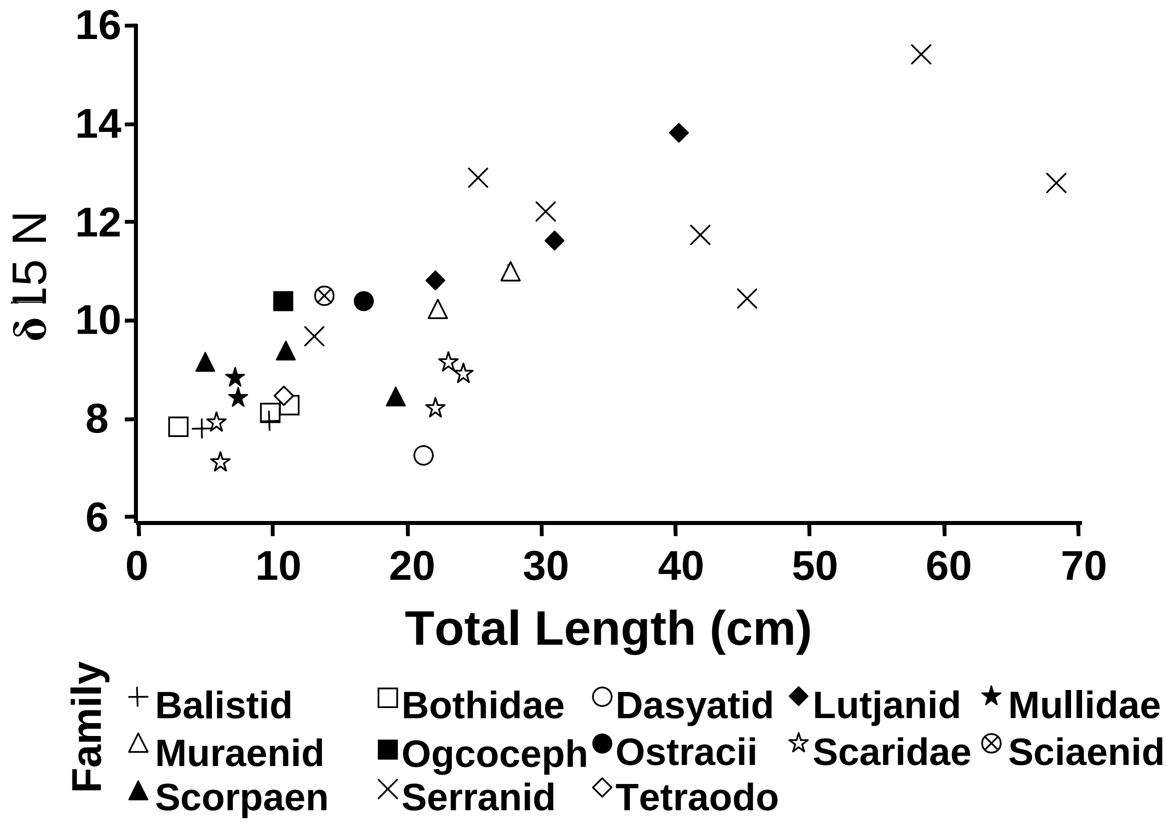


Figure 3. Nitrogen isotopic signatures by total length for various fish families found in TER.

Reef Fish

Although it is not possible to identify definitive changes in fish population dynamics after two years of protection, some interesting patterns have emerged. The numbers of fish > 20 cm total length appear to have increased in the new Reserve when compared to the Park and Open strata (Fig. 4). Six fish species (representing the most abundant species in each of six important reef fish families) show an increase in number and size within the Reserve when compared to the Park and Open strata (Fig. 5). In 2002, both large red and black grouper, on the order of five years old, were conspicuous parts of the fish assemblage at the reef soft bottom interface. In 2001, only large red grouper were abundant. The source of these differences could generally be attributed to the considerable natural variability of such systems, increasing grouper densities at interior reef sites, or movement with growth, of an exceptional year class of black grouper, to productive, though risky feeding habitat. The need for development of a longer-term data base is required to make effective comparisons among Use strata. Analysis of census data is ongoing at CCFHR.

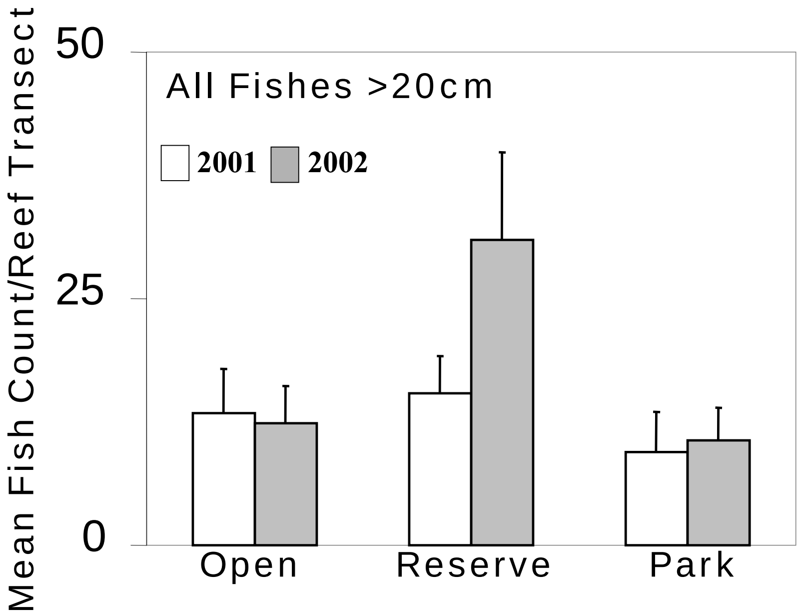


Figure 4. Mean number of fish (< 20cm) per transect, all species combined. N = 10 for each strata per year.

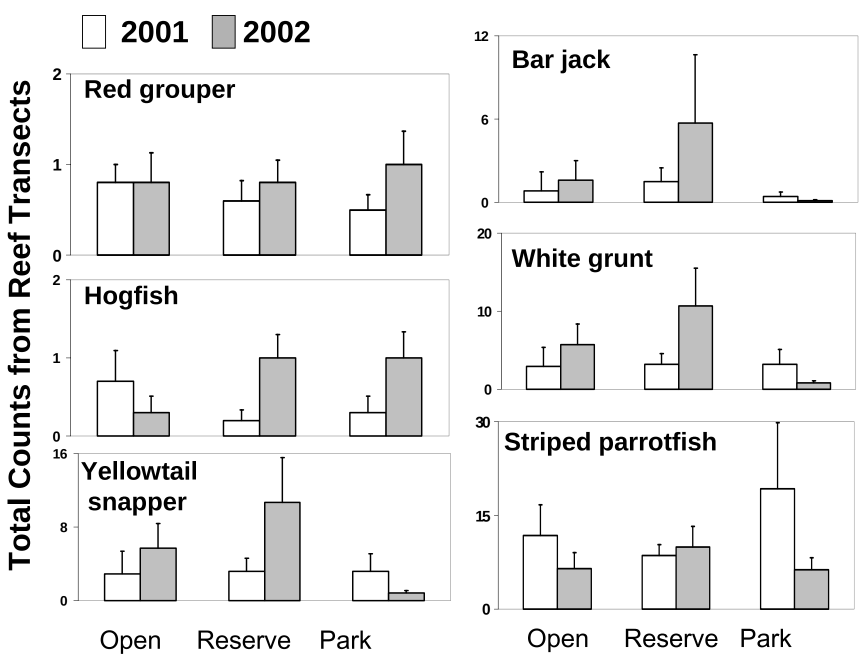


Figure 5. Total number of fish, by species, per transect for each strata per year.

Gear Impact

Our faunal collections from open and protected softbottom habitat near the northern boundary of Tortugas North strongly suggest that relaxation of trawling pressure has increased benthic biomass and diversity in this area of the TER. The Reserve may act as a refuge for large pink shrimp targeted by the fishery, and their density as well as biomass and diversity of smaller crustaceans was obviously higher in paired protected vs. open samples. Although not as obvious, differences in the fish and echinoderm assemblages between trawled and protected bottom are likely to become clear with the detailed analysis of our samples. It appears that these softbottom communities respond quickly to relaxation of the disturbance of trawling and we hypothesize that further changes will occur over time with development of a more stable assemblage of attached invertebrates that should develop in the more physically stable parts of the shelf. We believe that an increase in fishes and other benthic animals can be assumed to be occurring in protected habitats within the Reserve. However, we do not have replicate Ecological Reserves, and differences among samples taken within the TER versus those taken just out of the area may conceivably be an artifact of distance from reef structure. The final interpretation of these findings will, like other aspects of the study, rely on BACI design constraints. Moreover, whether or not the current reserve status of the TER is having a beneficial effect on the ecosystem in general and on targeted, long-lived reef predators will require continued assessment. Sample processing continues at CCFHR including new samples obtained in July 2003.

References

Cocheret de la Morinere, E., B.J.A. Pollux, I. Nagelkerken, M.A. Hemminga, A.H.L. Huiskes, and G. Van der Velde. 2003. Ontogenetic dietary changes of coral reef fishes in the mangrove-seagrass-reef continuum: stable isotopes and gut content analysis. Mar. Ecol. Prog. Ser. 246: 279-289.

Fry, B., R. Lutes, M. Northam, P.L. Parker. 1982. A $^{13}C/^{12}C$ comparison of food webs in Caribbean seagrass meadows and coral reefs. Aquat. Bot. 14: 389-398.

Fry, B., P.L. Mumford, and M.B. Robblee. 1999. Stable isotope studies of pink shrimp (*Farfantepenaeus duorarum* Burkenroad) migrations on the southwestern Florida shelf. Bull. Mar. Sci. 65: 419-430.

Meyer, J.L., E.T Schultz, and G.S. Helfman. 1983. Fish schools: an asset to corals. Science 220: 1047-1049.

Peterson, B.J., R.W. Howarth, and R.H. Garritt. 1985. Multiple stable isotopes used to trace the flow of organic matter in estuarine food webs. Science 227: 1361-1363.

Underwood, A.J. 1991. Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. Aust. J. Mar. Freshwat. Res. 42: 569-587.

Diadema Restoration Projects

Diadema Restoration Project

Brad Rosov (The Nature Conservancy [TNC], Sugarloaf Key, FL)

Project Goals/Narrative

Reef-building corals with their diverse growth forms are responsible for the structural relief that supports a high diversity of commercially, recreationally, and ecologically important organisms on coral reefs including groupers and snappers, lobsters, and sea turtles. Corals co-exist in a dynamic balance with reef algae, which are at the base of the coral reef food web. High levels of herbivory (grazing) are critical to maintaining competitive dominance of corals and to algal production fueling the coral reef food web. On Western Atlantic and Caribbean coral reefs, there have been recent shifts away from dominance by corals, and reefs have become dominated by thick turf and fleshy algae since the 1983 epizootic die-off of the major coral reef grazer, the sea urchin *Diadema antillarum*. The resulting alterations of coral reef substrate characteristics and trophic structure have impacted coral recruitment and survival of corals that do recruit. Effective ecological restoration of coral reefs may require the replenishment of critical/keystone members of the coral reef ecosystem, such as the herbivorous urchin *Diadema antillarum*. This urchin is still in low abundance on most coral reefs in the Caribbean, two decades after the mass die-off. Repopulation of *Diadema* may help create reef substrates more suitable for coral recruitment, prevent further smothering of corals, and improve the survivorship of recruited coral colonies in the Florida Keys. A desirable outcome of this project is to create a network of reefs within the Florida Reef Tract with locally high densities of adult *Diadema*. When *Diadema* spawns, these aggregations may serve as centers of dispersal by providing greater numbers of larvae for colonization of other reef and hard-bottom areas.

Methods

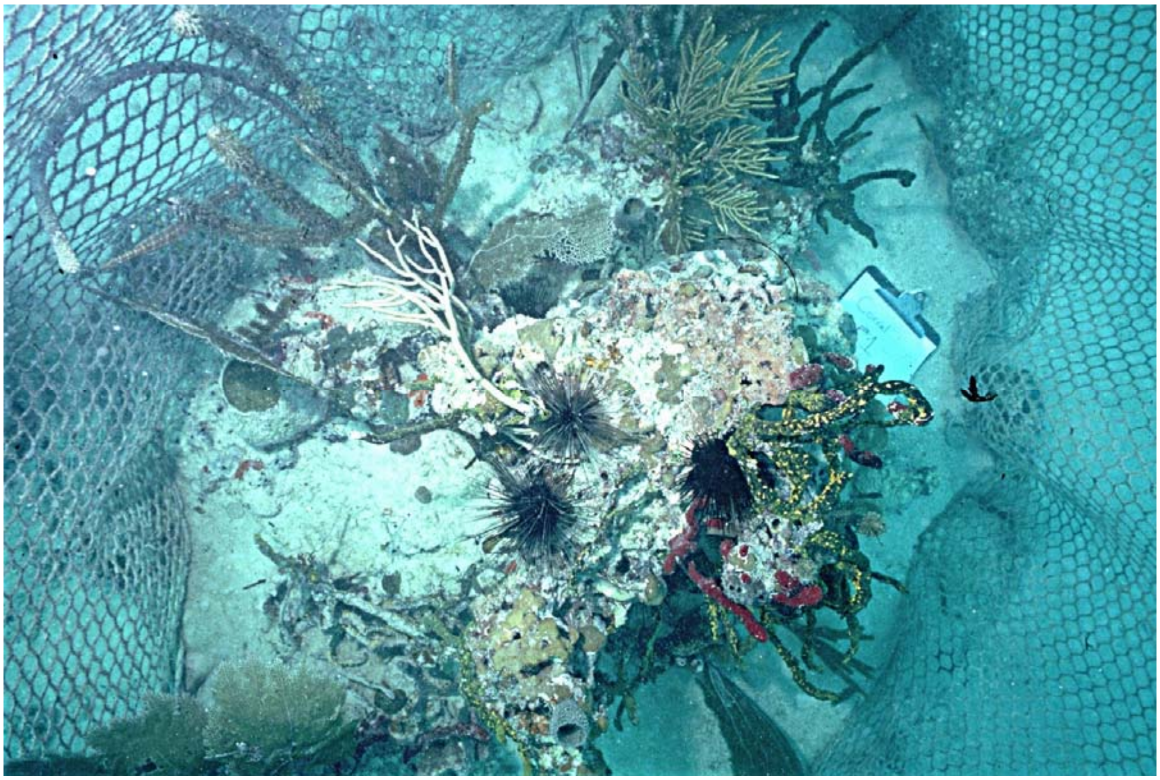
"Corrals" made of nylon mesh were deployed around four coral heads at a site with low coral cover located off of Big Pine Key in the Lower Keys. These corrals were stocked with densities of adult urchins approximating pre-die-off densities (approx. 4 individuals per m^2) (Photo 1). Four other coral heads were selected to act as controls for this project; they were not encircled with the corral material or stocked with *Diadema*. The benthic community within the corrals and controls was surveyed utilizing point-intercept transects conducted at monthly intervals to document substrate characteristics. It was hypothesized that algal communities would decrease in density within the corralled coral heads compared to untreated coral heads because of *Diadema* herbivory. Surveys were also conducted every week or two to assess the abundance of *Diadema* within corrals. As densities of *Diadema* fell below $4/m^2$, more urchins were collected and placed within corrals. Three months following the introduction of urchins into corrals, coral spawn was collected and coral larvae were introduced to the four corralled coral heads. The settlement and survivorship of juvenile corals was monitored sporadically. Lab-raised juvenile urchins were released into two separate corrals adjacent to the other four corrals utilized for the wild urchins. Survivorship of these lab-raised urchins was monitored on a regular basis.

Results

Results were measured in three ways: 1) changes to benthic communities within corrals and control areas, 2) survivorship of wild and lab-raised Diadema*, and 3) settlement and survivorship of the "seeded" corals.*

Photo 1: View of Corral #1 (Interior)

Legend: This is a photograph of corral #1. *Diadema* can be seen on top of the corralled coral head. The nylon mesh material used for the corral can be seen surrounding the coral head.



Changes to the Benthic Community

Point intercept transects were conducted every month within corrals and controls to determine changes in benthic communities over time. Corrals stocked with wild urchins displayed a drastic reduction of turf algae over a short period of time (Graph 1). In the initial survey of the four corralled areas, average cover of turf algae was 43%. The last survey was conducted 152 days later; cover of turf algae was reduced to 3%. The slope of the curve suggests that algal cover was reduced rapidly (within 60 days) following the inclusion of *Diadema*. The percentage of corals, sponges, gorgonians, and bare substrate within corrals remained relatively level throughout the duration of the project.

The results of benthic surveys of controls showed high variability of algal turf percentages (Graph 1). The percentage of corals, sponges, and gorgonians, and bare substrate remained relatively level throughout the entire project. The variability (standard deviation) of observations was quite high for most benthic surveys, for both corrals and controls; one factor for this may be inter-observer variability.

Survivorship of Diadema

Wild *Diadema* were collected from various sites throughout the Lower Keys and were placed within each of the four corrals. Initially, 32 urchins were collected and eight were placed into each corral (Graph 2). Twenty-nine days later, 21 more *Diadema* were added to the corrals to raise the densities to approximately $4/m^2$. As densities dropped over time due to predation, escapes, or natural mortality, 12 more urchins were collected and added to the corrals 104 days following the beginning of the project. The total number of *Diadema* collected was 65 and we could account for 34 individuals 174 days later, which corresponded to a loss rate of 48%. During an 18-day period (days 118 through 136), we lost 16 urchins, or 25%. It is unclear why losses increased so drastically during this short period of time. Prior to this sudden decrease, losses had been approximately 20% for the first 118 days of the project. Occasionally, *Diadema* were located outside of corrals and were presumed to have escaped. These animals were relocated into corrals.

Two additional corrals were constructed and used to contain a total of 27 lab-raised urchins. These *Diadema* exhibited a very high rate of loss (Graph 2). Over the course of several weeks, not one lab-raised urchin could be accounted for.

Coral Settlement and Survivorship

Coral spawn was collected from numerous individuals of *Montastrea* spp. The coral larvae were then released onto the corralled coral heads. The substrate on the coral heads was appropriate for coral settlement because of the high rate of herbivory by *Diadema*. Prior to seeding with coral larvae, areas were surveyed for existing juvenile corals to serve as a baseline. Following the coral spawn collection, it was estimated that over one million coral larvae were released onto the site. “Settlement tents” were used to confine larvae above coral heads until larvae naturally settled to the substrate. Two weeks after the larvae settled, pieces of coral rubble that were placed within the “seeded” area were removed and transported to a lab for inspection under dissecting microscopes. Settlers were observed (Photo 2). Three months later, the corralled areas were surveyed and many more juvenile corals (0.5-1.5 cm) were observed compared to the initial survey.

Graph 2: Total Number of *Diadema* Counted During Surveys

Legend: The blue curve illustrates the total number of wild *Diadema* observed within the four corrals over time. Note that 32 wild *Diadema* were placed within the four corrals initially. Twenty-one more were added to the corrals on day 29 and an additional twelve were added on day 104. The red curve illustrates the total number of lab-reared *Diadema* observed within two separate corrals over time. Twenty-seven lab-reared urchins were placed within these two corrals initially.

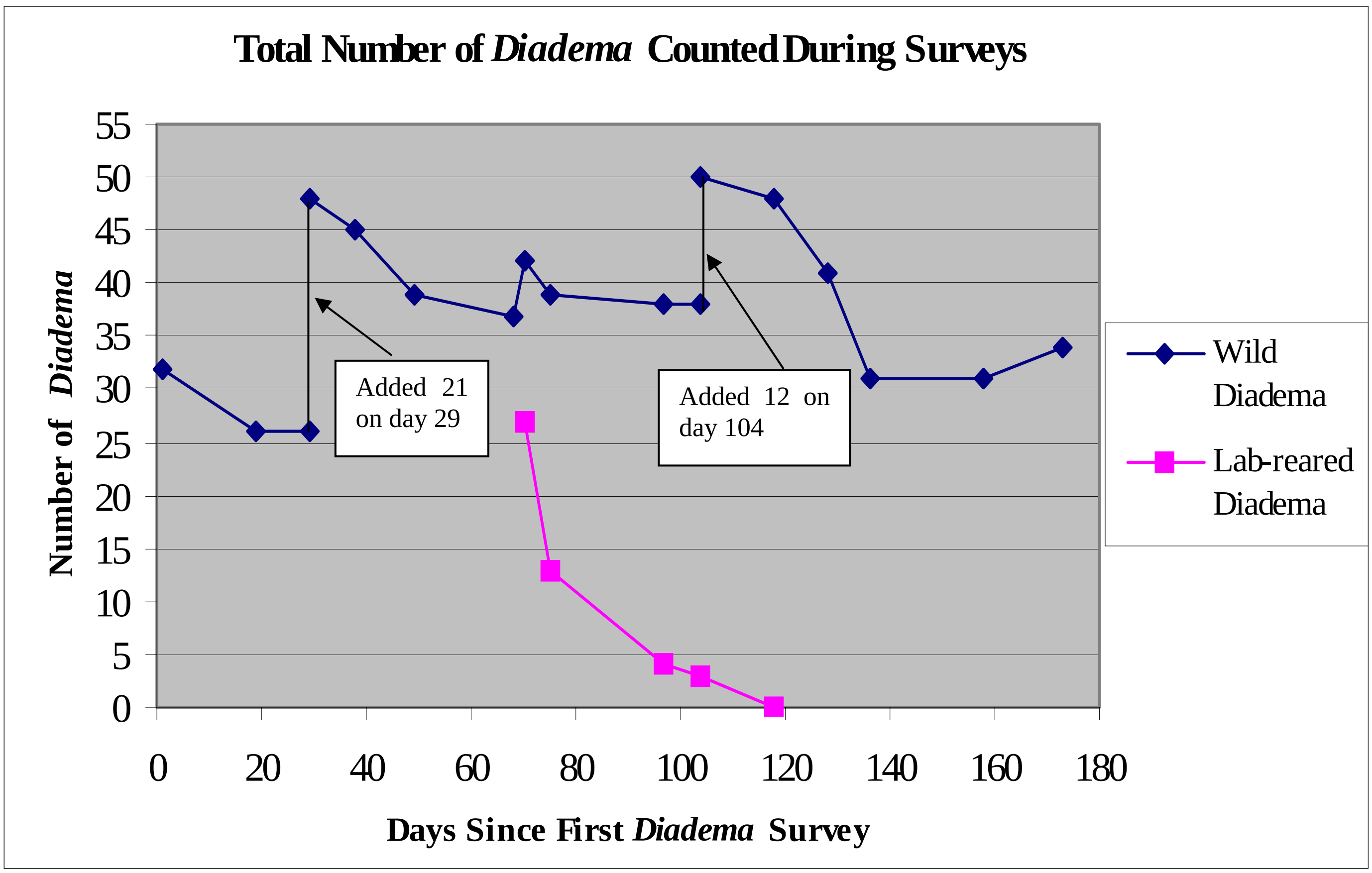
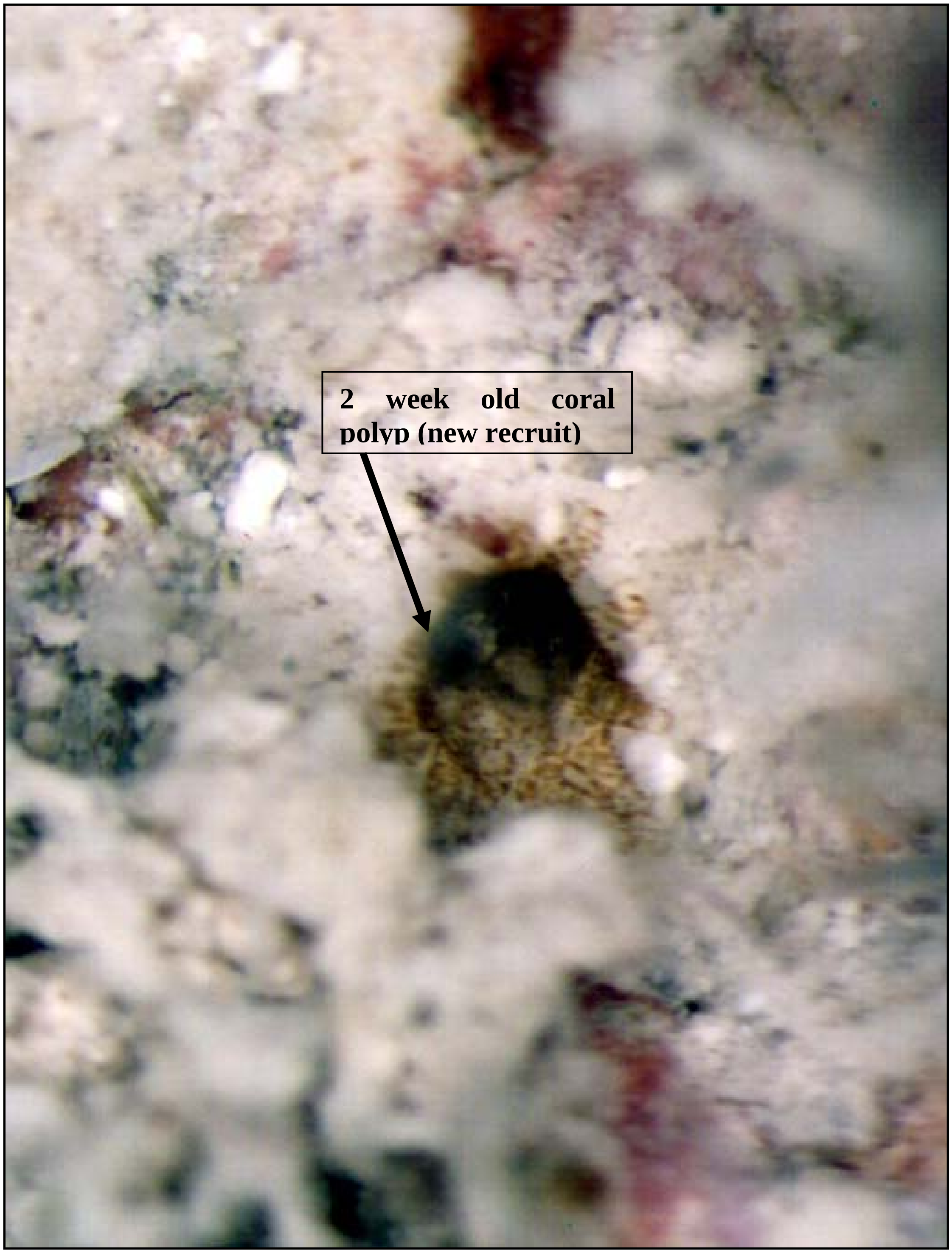


Photo 2: Two-Week Old Coral Polyp (New Recruit)

Legend: This is a micrograph of a two-week old juvenile coral that recently settled out onto substrate within the corralled area.



Techniques Development for the Re-establishment of the Long-spined Sea Urchin, *Diadema antillarum*, on Two Small Patch Reefs in the upper Florida Keys

Ken Nedimyer and Martin A. Moe Jr. (Sanctuary Advisory Council, FKNMS, Marathon, FL)

Abstract

A project was begun in the fall of 2001 offshore of the Upper Keys to explore the feasibility and ecological results of translocating juvenile long-spined sea urchins, *Diadema antillarum*, from areas with relatively high settlement and extensive winter mortality (reef crest rubble zones), to nearby deeper water (about 25 feet, 7.5 m) patch reefs at densities approaching those on Florida reefs before the *Diadema* die-off of the early 1980s. Four patch reefs, two experimental and two controls, varying in size from about 44 to 96 m^2 were selected for the study. From September 2001 to December 2001, 434 juvenile long-spined urchins were placed on Experimental Reef (ER) #1 (96 m^2), a total potential density of 4.5/m^2, and 262 were placed on ER #2 (88 m^2), a potential density of 3.0/m^2. An additional 16 urchins were placed on ER #2 on 10/23/02 bringing the total urchins placed on ER #2 to 278, a potential density of 3.2/m^2. The translocated populations were evaluated for number and placement of surviving urchins 10 times on ER #1 and 11 times on ER #2 over various intervals from 9/8/01 to 2/5/03.

Survival of *Diadema* was roughly similar on both experimental reefs from the first count on 9/8/01 through the final count on 2/5/03. Survival rates over the first three days of 80% and 93% dropped to about 40-45% on both reefs from 11/09/01 to 05/29/02, and then, on ER #1, survival remained at about 30% from 8/8/02 to 2/5/03. On ER #2, survival remained at 40% on 8/8/02, dropped to 30% on 10/8/02, and then dropped again to 17% on 11/30/02. Survival was 20% on 2/5/03 because of placement of 16 urchins on this reef late in the study (10/23/02). The average density of urchins over the entire 17 months of the study was 1.6m/^{2} on ER #1 and 1.0/m^2 on ER #2. The highest density on ER #1 (2.1/m^2) occurred on 2/26/02; ER #2 a maximum of 1.4/m^2 occurred on 10/24/01 and on 2/26/02. The final density (2/5/03) on ER #1 and #2 was 1.2/m^2 and 0.6/m^2, respectively. Decline in survival and density on both reefs was generally gradual and stable at a similar rate of decline during the last 12 months of the study. ER #1 lost 87 urchins, a survival of 57% over the last 345 days of the study. The total loss in urchin density on ER #1 over this period, 2/26/02 to 2/5/03, was 0.9/m^2, which was a decline in density of 0.0026/m^2 per day. ER #2 lost 67 urchins during this 345-day period, a survival of 45% and a loss in density of 0.8/m^2; which was a decline in density of 0.0023/m^2 per day (the data for ER #2 includes 16 urchins released on 10/23/02).

The gradual urchin mortality over the term of the project indicated that predation was the main cause of population decline and not mortality due to storms. Population counts before and after two instances of tropical storm conditions in the fall of 2001 indicated that these storms did not cause mortality in the translocated urchin populations on the experimental deep reefs. Also, no evidence of disease-caused *Diadema* mortality was observed.

Although evidence of some movement between reef quadrants and some concentration of urchins on the more rugged and complex areas of ER #1 was evident, in general, urchins remained broadly distributed over all reef areas on each experimental reef.

The NOAA National Undersea Research Center at Key Largo (NURC) conducted rapid ecological assessments of the four project reefs on 8/31-9/1/01, before translocation of urchins and again on 9/18/02, about one year after translocation of urchins (see next chapter). The benthic ecology of the experimental reefs changed considerably during the period of exposure to "normal" pre-die-off densities of *Diadema*. These changes on the experimental *Diadema*-addition reefs over the short term of one year included a marked reduction in brown foliose algal cover, and a return toward coral-dominated benthic cover as expected from a return of *Diadema* to the reefs. They reflected changes that have occurred on limited areas of Caribbean reefs such as Jamaica where populations of *Diadema* have returned naturally. This study presents evidence that translocation of *Diadema* from environments with high risk of mortality to deeper reef areas along the Florida Keys resulted in survival and population densities that can affect change in the ecology of coral reefs, by transforming reef areas from algal dominance toward coral dominance.

Introduction

Coral reefs that compose the reef tract of the Florida Keys have been in decline for several decades. The reasons for this decline are many and varied; some are well documented and some are speculative. However, one factor strongly contributing to the decline of Caribbean, Bahamian, and Florida coral reefs has been attributed to the almost total loss, 97 to 99%, of the long-spined sea urchin, *Diadema antillarum*, in an unprecedented disease pandemic on a single marine organism that occurred in 1983-84. *Diadema* was a keystone herbivore in this region, and the loss of this animal shifted the balance on reefs from coral dominance to extensive macroalgal growth. Despite the passage of 20 years and the sporadic and variable presence of small pockets of *Diadema* in the Florida reef environment, this keystone herbivore has not repopulated reefs and macroalgae continue to dominate most coral reefs in this ecosystem.

In the fall of 2000, we began work on a project to establish a pre-die-off population level of *Diadema* on two small patch reefs in the Upper Keys. The purpose of this project was to explore the survival of translocated urchins in this environment and the effects that this urchin population may have on the benthic ecology of these reefs. The Florida Keys National Marine Sanctuary (FKNMS) and the NOAA National Undersea Research Center at Key Largo (NURC) aided in the design of the project. The rationale for the project was to collect juvenile *Diadema antillarum* from shallow rubble areas on the reef crest where they settle in the late summer and fall, but apparently do not survive the fall and winter storms that churn this area, and translocate them to deeper patch reefs. Two experimental and two control reefs were selected for this work.

The overarching goal of this project was to monitor and track the success of one technique to enhance and restore coral reef areas. Specifically, the transplantation of large numbers of small *Diadema antillarum* from shallow rubble zones to deeper patch reefs will be evaluated. An additional goal was to monitor the resulting effects of increased densities of *Diadema antillarum* to determine if a reduction of algal overgrowth will enhance coral growth and settlement.

There were four specific biological objectives in this project:

- Determine if *Diadema* survive transplantation and the size that exhibits the best survival rate after transplantation
- Estimate the survival and growth rates of transplanted *Diadema*

- Determine the distribution patterns that *Diadema* develop on test reefs
- Compare and contrast general reef condition and community level changes, including coral recruitment and growth, on the manipulated and reference reefs over time.

Methods

Patch reefs about four miles eastward and offshore of Tavernier, FL, were explored and examined during the spring and summer of 2001 and four small patch reefs were selected for this project. Two of these reefs were designated as the experimental reefs (ER #1 and #2) and two as the reference (control) reefs (CR #3 and #4). The two experimental reefs were superficially different; ER #1 (about 96 m^2) was relatively rugged and contained some large coral formations mostly at the southern end while ER #2 (about 88 m^2) exhibited lower relief without the large *Montastraea cavernosa* boulder corals that occupied ER #1. The two control reefs were located in the same vicinity as the experimental reefs. CR #3 (about 72 m^2) was generally similar to ER #2, while CR #4 (about 44 m^2) was generally similar to ER #1. The maximum relief reported by the NURC surveys (Table 1) was about 80 cm for ER #1, compared to 62 cm for CR #4, and about 43 cm for ER #2 compared to about 43 cm for CR #3.

Table 1. Physical characteristics of experimental (top) and control (bottom) patch reefs, expressed in terms of the mean (1 SE) minimum and maximum depth of surveyed transects, mean (1 SE) maximum vertical relief, and estimated mean (1 SE) percentage of site with given topographic relief. Data are based upon surveys of four 10 m x 0.4 m transects per site each year.

Experimental patch reefs

Physical variable	**Experimental reef #1**		**Experimental reef #2**		**Combined experimental**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
Minimum depth (m)	7.5 (0.0)	7.7 (0.1)	7.4 (0.1)	7.6 (0.1)	7.5 (0.1)	7.7 (0.1)
Maximum depth (m)	7.6 (0.1)	8.0 (0.1)	7.5 (0.0)	8.0 (0.1)	7.6 (0.1)	8.0 (0.0)
Maximum relief (cm)	82 (16)	79 (13)	41 (7)	45 (4)	62 (21)	62 (17)
Relief area (%)						
< 0.2 m	72.5 (4.3)	61.3 (8.3)	63.8 (7.2)	70.0 (7.4)	68.2 (4.4)	65.7 (4.4)
0.2-0.5 m	25.0 (4.6)	23.8 (5.5)	35.0 (7.1)	28.8 (7.5)	30.0 (5.0)	26.3 (2.5)
0.5-1.0 m	1.3 (1.3)	15.0 (6.1)	1.3 (1.3)	1.3 (1.3)	1.3 (0.0)	8.2 (6.9)
1.0-1.5 m	1.3 (1.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)
> 1.5 m	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Control patch reefs

Physical variable	**Control reef #3**		**Control reef #4**		**Combined control**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
Minimum depth (m)	7.4 (0.1)	7.5 (0.0)	8.0 (0.1)	7.7 (0.1)	7.7 (0.2)	7.6 (0.1)
Maximum depth (m)	7.5 (0.0)	7.5 (0.0)	8.1 (0.0)	7.8 (0.0)	7.8 (0.2)	7.7 (0.1)
Maximum relief (cm)	42 (6)	44 (7)	63 (17)	61 (19)	53 (11)	53 (9)
Relief area (%)						
< 0.2 m	77.5 (3.2)	78.8 (4.7)	76.3 (7.2)	83.8 (5.5)	76.9 (0.6)	81.3 (2.5)
0.2-0.5 m	21.3 (2.4)	18.8 (2.4)	17.5 (6.0)	10.0 (2.0)	19.4 (1.9)	14.4 (4.4)
0.5-1.0 m	1.3 (1.3)	2.5 (2.5)	5.0 (2.0)	6.3 (3.8)	3.2 (1.9)	4.4 (1.9)
1.0-1.5 m	0.0 (0.0)	0.0 (0.0)	1.3 (1.3)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)
> 1.5 m	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Each of the four project reefs was carefully mapped and photographed before translocation of *Diadema* was begun. A sub-surface buoy was placed on each reef to mark the location without an attention-generating surface marker. A north–south and an east–west transect line was established at about the center of each reef, dividing each reef into four quadrants. Each of these quadrants, NW, NE, SW, and SE, was then marked off into 4-m^2 divisions to facilitate accurate recording of placement and subsequent location of *Diadema* during counts. Each experimental reef fit into a rectangle composed of 30 4-m^2 sectors, as six columns of sectors along the north–south axis and five rows of sectors along the east–west axis. On ER #1 the north–south axis was situated along the line dividing three columns of 4-m^2 sectors to the west and two columns of sectors to the east. On ER #2 the north–south axis divided the reef into two columns of sectors to the west and three columns to the east. The east–west axis on both ER #1 and #2 divided the reef in the center, three rows of sectors to the north and three rows to the south. A square pvc-pipe frame 2 m on each side was used to measure and temporarily demark each 4-m^2 sector and served as a frame for photographs. A map of the location and approximate size of the coral formations that composed each reef was recorded in situ with pencil on a plastic slate on which the 4-m^2 sectors and 120-m^2 total area were inscribed with a permanent marker. Later, representations of coral formations were traced with a permanent marker and a permanent map of each reef was drawn on a plastic slate.

These reefs were not exactly rectangular in shape; there were areas of dense hard and soft coral structure exhibiting rugged relief, areas of low relief with scattered coral formations, and some areas with only seagrass and sand bottom within the delimited grid pattern of the reef. For the purpose of determining the density of *Diadema* on each reef and on each quadrant of each reef, 4-m^2 sectors that contained little or no reef structure on the periphery of the reefs were eliminated from calculations of reef area.

Six of these 4-m^2 sectors were omitted from ER #1, resulting in a total reef area of 96 m^2: one sector from the NW quadrant (resulting reef area of 32 m^2); one from the NE quadrant (resulting in 20 m^2); three from the SW quadrant (resulting in 24 m^2; and one from the SE quadrant (resulting in 20 m^2). For ER #2, which was smaller in extent and structure than ER #1, a total of eight 4-m^2 sectors were omitted, resulting in a total reef area of 88 m^2: one sector from the NW quadrant (resulting in 20 m^2); three from the NE quadrant (resulting in 24 m^2); one from the SW quadrant (resulting in 24 m^2); and three from the SE quadrant (resulting in 20 m^2). Figure 1 illustrates the working map of each experimental reef, including demarcation of the 4-m^2 sectors omitted from reef area determinations.

Juvenile *Diadema* were collected from shallow rubble zones at the reef crest at Conch and Pickles Reefs during 10 trips to one or both sites from September to December 2001 (Table 2). Urchins were collected by carefully removing them from under or between rubble with a short aluminum rod and flipping them into a large, small-mesh hand net. When the net was full, the urchins were taken to a boat, placed in holding tanks, and sorted by size: small (test size about 1 to 2.5 cm), medium (2.6 to 4.0 cm), and large (4.5 to 6 cm). Usually, two collectors worked the rubble bottoms and one additional person in the boat helped to transfer the urchins to the holding tanks. Effort (Table 2) consists only of the total collector hours expended during each collection trip (one-three collectors). A total of 30 collection hours were expended to collect 741 urchins. There was an average yield of 25 urchins per collector-hour.

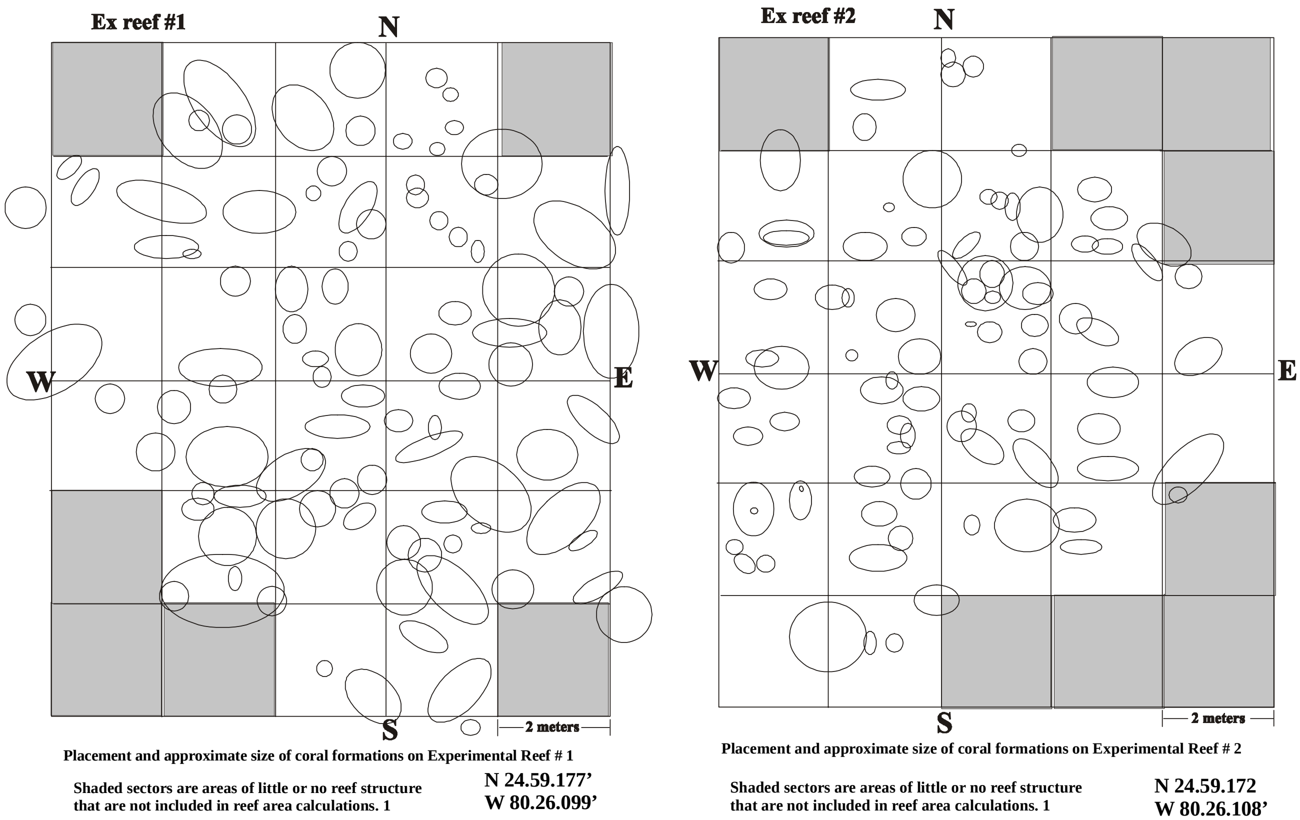


Figure 1. Working map of experimental reefs #1 and #2.

Table 2. Collection data for juvenile *Diadema antillarum* at Pickles and Conch reefs.

Date 2001	Conch Reef	Pickles Reef	small (1–2.5 cm)	medium (2.6–4.0 cm)	large (4.5–6+ cm)	effort in collector hours
09/04		162	43	102	17	6.0 hrs
09/05		123	23	93	7	6.0 hrs
09/17	11			11		0.5 hrs
09/19	75		58	13	4	2.0 hrs
09/21	105		32	33	40	6.0 hrs
09/26	78		53	14	11	1.5 hrs
10/05	41		15	5	21	1.5 hrs
10/24		55	22	14	19	2.0 hrs
12/14	17		1	6	10	0.5 hrs
12/20	74		2	15	57	4.0 hrs
Totals	401	340	249	306	186	30.0 hrs

Immediately after collection, the urchins were transported by boat to the experimental reefs. Divers carried the urchins down to the reefs, where they were placed next to coral formations. Upon being released from nets, urchins immediately moved toward and into nearby coral structures. No urchin seemed to be exposed without shelter for more than a few minutes. No predation on newly released urchins was observed. The specific location of release of each urchin was recorded a map of the reef (see Fig. 1).

Counts of urchins on the experimental reefs were made at various intervals as weather and opportunity allowed beginning a few days after the first translocation on 9/8/01 until 2/5/03 (Table 3). When a count (population evaluation) was made on the same day as a collection of juvenile urchins, the count of the surviving *Diadema* population on the reefs was made before release of the collected juvenile urchins. An exception to this occurred on 10/24/01 at ER #2. In this instance, to prevent inflation of the survival estimate, the number of urchins released was subtracted from the number counted on that date. Also, 16 urchins released on ER #2 on 10/23/02 were subtracted from the count on 11/30/02 to provide more accurate survival data.

A total of 11 counts (10 on ER #1 and 11 on ER #2) were made over the course of the project. Each quadrant of the experimental reefs was carefully surveyed and the presence and location of every urchin observed was recorded.

Table 3. Translocation and survival data of *Diadema antillarum* on the two experimental reefs, 9/4/01 to 2/5/03.

Date	Experimental Reef #1 (96 m^2)				Experimental Reef #2 (88 m^2)			
	total released before count (#R)	total count (#C)	% survival (#C/#R)	# released this date (after count)	total released before count	total count	% survival (#C/#R)	# released this date (after count)
09/04,5/01				201				85
09/08	201	160	80		85	79	93	
09/17				11				
09/19	212	172	81		85	79	93	27
09/21								105
09/26				79				
10/05				42				
10/24				34	217	134	62	21*
11/09	367	161	44		238	118	50	
12/14				17				
12/20	384	175	46	50	238	106	45	24
02/26/02	434	202	47		262	122	47	
05/29	434	181	42		262	109	42	
08/08	434	135	31		262	103	39	
10/08	434	122	28		262	77	29	
10/23								16
11/30	434	119	27		278/262	63/47	23/18	
02/05/03	434	115	26		278	55	20	
Totals				434				278/262**

*The 21 urchins released on this date were included in the count on this date. For this table these 21 urchins were subtracted from the number released and from the number counted.
**The 16 urchins released on 10/23/02 were not included in data analysis of 11/30/02.

An extensive series of photographs was made of each experimental reef before placement of the urchins and then at various times after their placement. The reefs were not disturbed by collection of organisms or relocation of any urchins after initial placement. Two exceptions to this were the removal of two large spotted burrfish, *Chilomycterus atinga*, the first on 9/3/01, the day before initial placement of urchins on the reef, and the second during a night dive on 9/28/02. The first burrfish was removed from the NE quadrant of ER #1 where there was evidence (crushed coral and broken shells) that the burrfish frequently occupied a specific sheltered area under a coral formation. The second was also removed from ER #1 as it moved about this area during the night. It also apparently frequented the same sheltered coral cave area on the NE quadrant as the first burrfish, as crushed shells and urchin spines were present. Remains of freshly crushed urchins on ER #2 indicated that the burrfish also frequented this nearby reef. The second burrfish was taken immediately after feeding on urchins since bits of *Diadema* test and spines were present in the area where it was taken and also found later on the bottom of the holding tank where it was placed after capture.

Long view of Experimental Reef #1.

Documentation of the benthic communities of the experimental and reference reefs was conducted by NURC on 8/31-9/1/01 before placement of urchins on the experimental reefs and again on 9/18/02, about one year after placement of *Diadema* on the experimental reefs. The following chapter details changes that occurred on experimental and reference reefs during the first year of this project.

Results

The results of this project fall into two basic categories: the progressive survival and status of *Diadema* populations on the experimental reefs, and the analysis and documentation of the condition and changes in benthic communities on the experimental and reference reefs (see next chapter).

Diadema *Populations on the Experimental Reefs*
Collection of juvenile *Diadema* from the shallow rubble zones during good weather and sea conditions was not physically or technically difficult. Juveniles were variously abundant in these areas during late summer, fall, and early winter depending on settlement success and occurrence and intensity of storms during this period. Table 2 (above) presents the collection data and effort in collector hours for the juvenile *Diadema* collected during the first four months of the project. Small *Diadema* (test size under about 2.5 cm in diameter) are very secretive and can be difficult to find. Although an average of 25 urchins per collector-hour were taken, an experienced collector, depending on conditions, would be considerably more productive than a novice collector. Also, the numbers of juvenile urchins in these shallow rubble zones varied considerably depending on strength of recruitment, occurrence of storms, depth, and season. When juvenile urchins were abundant, large numbers could be quickly collected and when they were scarce, collection was more time consuming.

We intended to attain a density of about 4 *Diadema* per square meter on each experimental reef to approximate reported, near-maximum, pre-die-off densities on Florida Keys reefs of 4-5/m^2. With limited collection effort, juvenile *Diadema* were available in the rubble zones of Conch and Pickles Reefs during the early fall of 2001 in just enough abundance to provide the desired pre-die-off *Diadema* density (about 3-4.5/m^2) on each reef. Despite high mortality in the first few months, a sustained average density of 1-2 urchins/m^2 (1.7/m^2 on ER #1 and 1.1/m^2 on ER #2) was maintained over the course of the project.

Table 3 (above) presents data on the total numbers of *Diadema* released on ER #1 and #2, the numbers counted at each population evaluation on each reef, and the percent apparent survival rate of the urchins on each reef at the time of each count. The survival rate is termed "apparent survival" because it is quite possible, especially when early juveniles were abundant, that some urchins were deeply hidden in the reef structure and were not observed. The survival rate may have been slightly higher, but not lower than that recorded. Figures 2 and 3 show cumulative numbers of urchins released on ER #1 and ER #2, respectively, and counts at each survey; Figure 4 combines these data for both experimental reefs. Figure 5 presents percent apparent survival based on density (#/m^2 counted/#/m^2 released x 100) for both experimental reefs, and Figure 6 shows the changes in density of *Diadema* on each experimental reef over the course of the study.

Survival, Distribution, and Movement of Diadema *on the Experimental Reefs*
Survival rates were high during the first weeks after initial translocation of urchins to the experimental reefs. The initial translocation of juvenile *Diadema* occurred on 09/04/01 and 9/5/01. A total of 201 (plus 11 on 9/17/01) were placed on ER #1 and 85 were placed on ER #2. Percent apparent survival on ER #1 by density (#/m^2 counted/#/m^2 released x 100) over the first 14 days (9/05 to 9/19/01) was 82% on ER #1 and 90% on ER #2 (Table 3).

Storm Mortality
The upper Florida Keys were brushed by two fall storms early in the project, strong Tropical Storm Gabrielle on 9/14/01, and Hurricane Michelle on 11/5/01. The Upper Keys area experienced sustained winds of about 25-30 knots and gusts of about 40 knots during both storms. There was evidence of the effects of storm surges (sedimentation, movement of some

corals and rocks, and accumulations of loose seagrass and seaweed) on the experimental reefs after both storms.

Figure 3. Reef # 2: Total Diadema released (cumulative) and counted at each population evaluation.

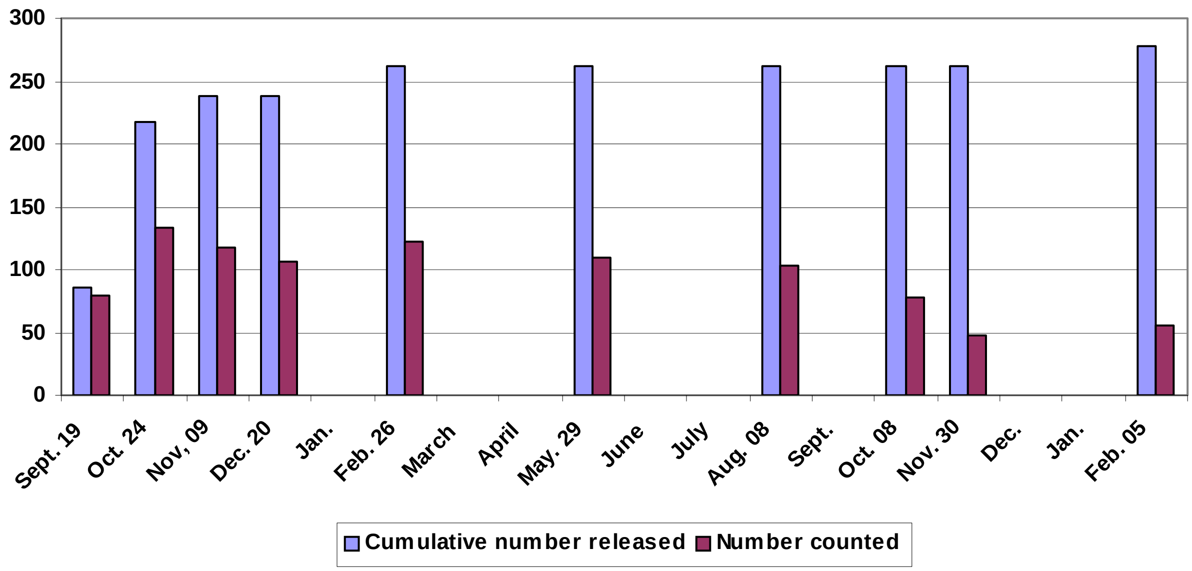


Figure 4. Reefs # 1 & #2: Combined release (cumulative) and count data at each population evaluation.

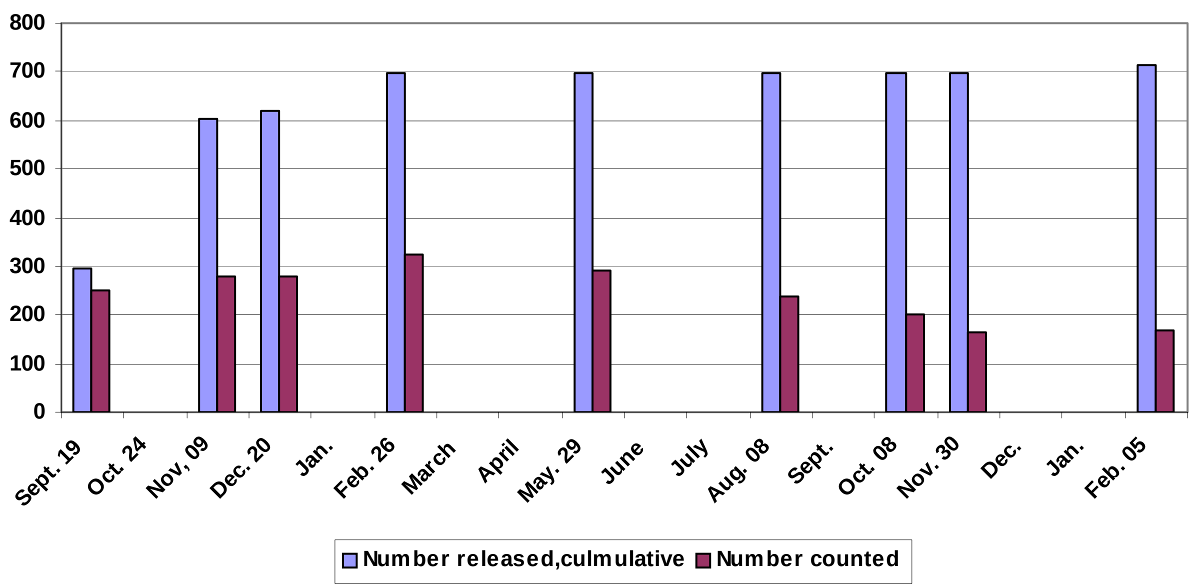


Figure 5. Percent apparent survival of Diadema by density (#/sq. m counted / #/sq. m released) at each count on reefs # 1 and # 2.

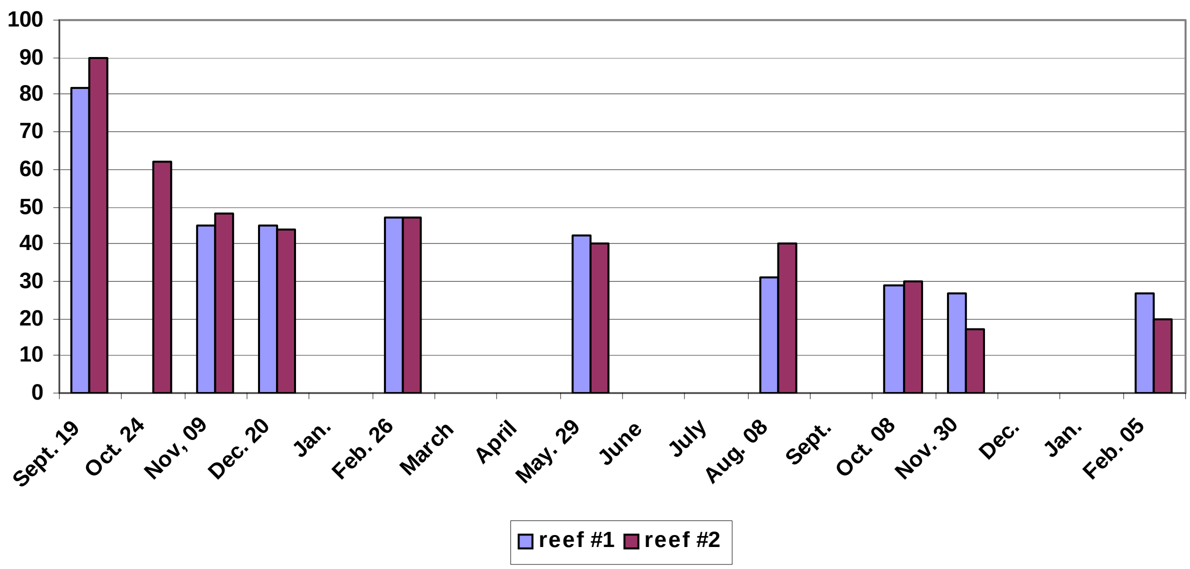
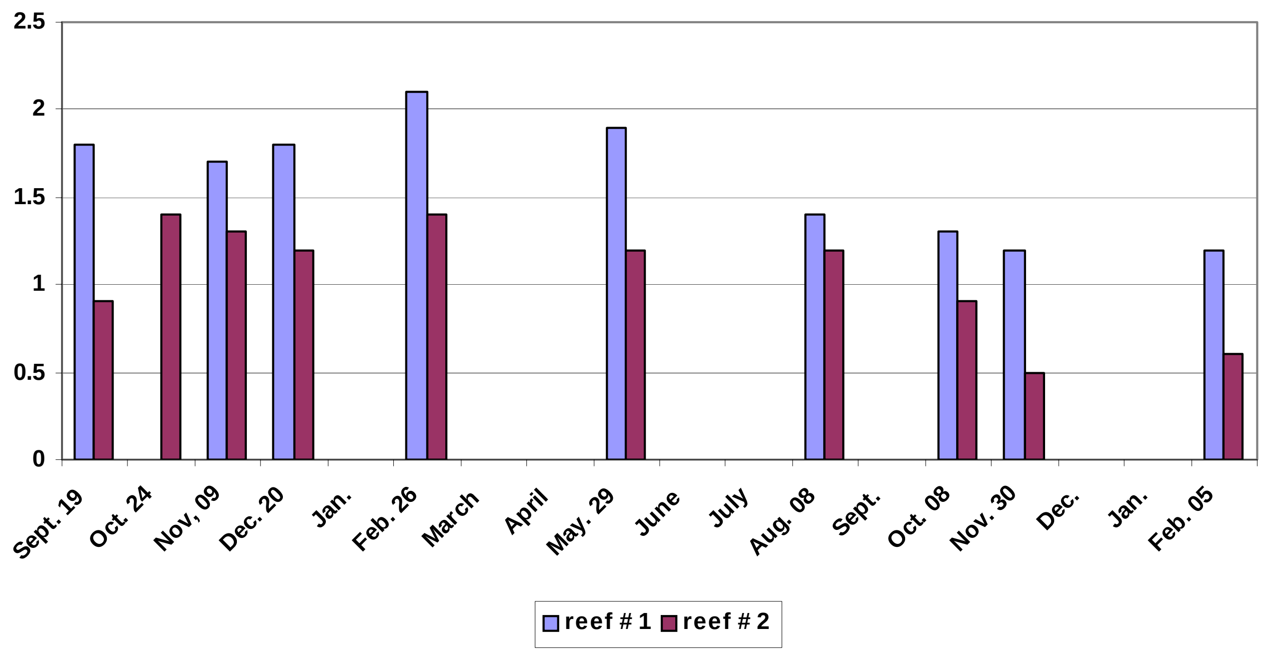


Figure 6. Density (#/sq. m) of Diadema on each experimental reef at each count.



Tropical Storm Gabrielle passed westward over the center of the Florida peninsular, well north of the Keys, which experienced the very fringes of the southern side of the storm, with winds mostly southerly. Loss of *Diadema* on the experimental reefs due to T.S. Gabrielle was minimal or none as the percent apparent survival on ER #1 and #2 on 9/8/01 were, respectively, 81% (1.7/m^2) and 90% (0.9/m^2) and the first counts after the storm 5 days later on 9/19, were 82% (1.8/m^2) and 90% (0.9/m^2) showing no loss in density (Tables 4 and 5). There was a release of 11 urchins on the NW quadrant of ER #1 on 9/17 after the storm (Table 6), and this is reflected in the increase in density on the NW quadrant in the 9/19 count from 1.8/m^2 (82% survival) to 2.2/m^2 (88% survival) an actual increase of 15 urchins on this quadrant. There was no loss in apparent survival or density of urchins on either reef before and after the storm; apparently there was no mortality due to passage of this storm. This indicates that urchins on the deeper patch reefs can survive a significant storm event with no apparent mortality.

Table 4. ER #1: percent change in density (% Sur, apparent survival) of *Diadema* (#/m^2 counted / #/m^2 released x100) on each quadrant and on the total reef area, including density released (R#/m^2) and counted (C#/m^2) on the total reef area.

Quadrant	NW 32 sq. m	NE 20 sq. m	SW 24 sq. m	SE 20 sq. m	total reef area 96 sq. m		
Date	% Sur	% Sur	% Sur	% Sur	R#/m^2	C#/m^2	% Sur
09/08/01	82	78	93	68	2.1	1.7	81
09/19	88	65	67	92	2.1	1.8	82
11/09	39	49	43	47	3.8	1.7	45
12/20	33	44	65	53	4.0	1.8	45
02/26/02	41	38	73	45	4.5	2.1	47
05/29	34	36	67	41	4.5	1.9	42
08/08	25	22	57	34	4.5	1.4	31
10/08	18	24	50	32	4.5	1.3	29
11/30	16	25	40	34	4.5	1.2	27
02/05/03	14	20	47	36	4.5	1.2	27

Table 5. ER #2: percent change in density (% Sur, apparent survival) of *Diadema* (#/m^2 counted / #/m^2 released x 100) on each quadrant and on the total reef area, including density released (R#/m^2) and counted (C#/m^2) on the total reef area.

Quadrant	NW 20 sq. m	NE 24 sq. m	SW 24 sq. m	SE 20 sq. m	total reef area 88 sq. m		
Date	% Sur	% Sur	% Sur	% Sur	R#/m^2	C#/m^2	% Sur
09/08/01	88	80	80	140	1.0	0.9	90
09/19	125	80	70	120	1.0	0.9	90
10/24	55	79	65	42	2.3	1.4	61
11/09	55	55	29	55	2.7	1.3	48
12/20	28	48	33	69	2.7	1.2	44
02/26/02	45	52	38	53	3.0	1.4	47
05/29	52	42	31	41	3.0	1.2	40
08/08	34	42	46	38	3.0	1.2	40
10/08	21	32	35	29	3.0	0.9	30
11/30	24	19	19	12	3.0	0.5	17
02/05/03	10	19	23	29	3.2	0.6	20

Table 6. ER #1: number of *Diadema* released, cumulative (#Rel), density released (#/m^2), actual number counted, (Cnt), and number present per square meter (#/m^2) on each quadrant at each population evaluation.

Quadrant	NW 32 sq. m				NE 20 sq. m				SW 24 sq. m				SE 20 sq. m			
Date	#Rel	#/m^2	#Cnt	#/m^2	#Rel	#/m^2	#Cnt	#/m^2	#Rel	#/m^2	#Cnt	#/m^2	#Rel	#/m^2	#Cnt	#/m^2
09/08/01	70	2.2	56	1.8	45	2.3	36	1.8	37	1.5	34	1.4	49	2.5	34	1.7
09/19	81	2.5	71	2.2	45	2.3	30	1.5	37	1.5	25	1.0	49	2.5	46	2.3
11/09	120	3.8	47	1.5	94	4.7	46	2.3	56	2.3	23	1.0	97	4.9	45	2.3
12/20	127	3.9	43	1.3	99	5.0	44	2.2	56	2.3	35	1.5	102	5.1	53	2.7
02/26/02	142	4.4	58	1.8	109	5.5	42	2.1	71	3.0	53	2.2	112	5.6	49	2.5
05/29	142	4.4	47	1.5	109	5.5	40	2.2	71	3.0	47	2.0	112	5.6	47	2.3
08/08	142	4.4	34	1.1	109	5.5	23	1.2	71	3.0	40	1.7	112	5.6	38	1.9
10/08	142	4.4	27	0.8	109	5.5	25	1.3	71	3.0	35	1.5	112	5.6	35	1.8
11/30	142	4.4	23	0.7	109	5.5	28	1.4	71	3.0	31	1.3	112	5.6	37	1.9
02/05/03	142	4.4	19	0.6	109	5.5	21	1.1	71	3.0	35	1.4	112	5.6	40	2.0
mean				1.3				1.7				1.5				2.1

Hurricane Michelle passed westward through the Florida Straits on 11/5/01 about 100 miles SE of the upper Florida Keys. The Florida Keys were on the northern side of the storm and experienced strong northeasterly winds gusting to 50 knots (Molasses Reef) and storm surges of 1-3 feet (storm data from the NOAA Tropical Weather web site). The impact of H. Michelle to the Upper Keys appeared to be greater than the impact of T.S. Gabrielle.

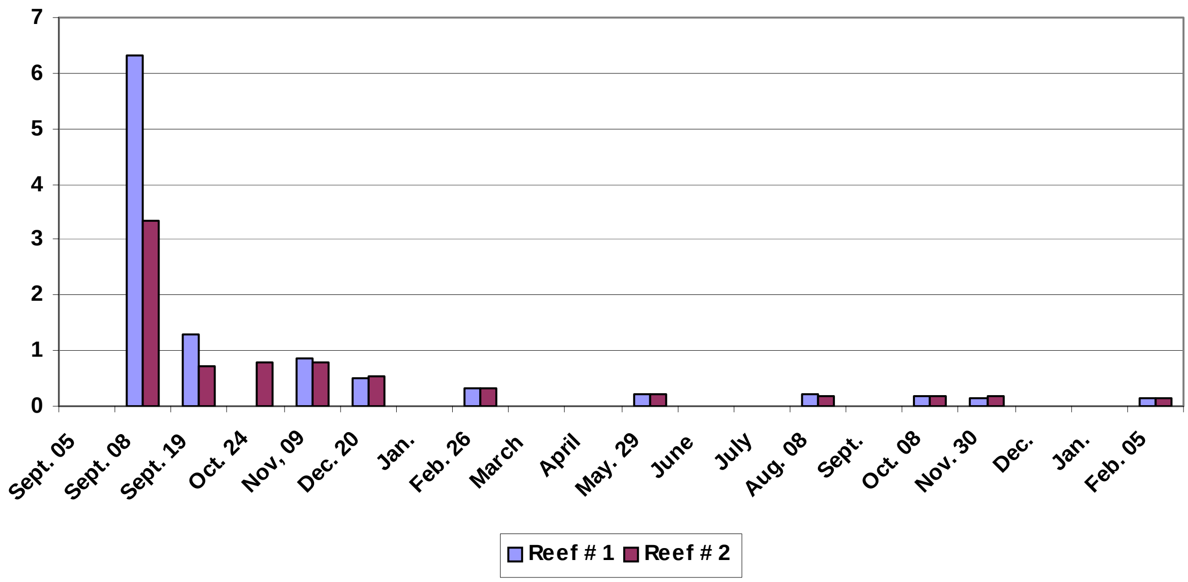
Diadema survival on ER #1 dropped from 82% on 9/19 to 45% on 11/9/01, 51 days later (4 days after H. Michelle; Table 4). During this 51 days, however, 155 additional urchins were translocated to ER #1 (between 09/26 and 10/24; Table 3), so although the percent survival (calculated as the #/m^2 counted/#/m^2 released x 100) dropped by 37% over this period, the overall density of urchins on the reef dropped by only 0.1/m^2 (1.8/m^2 to 1.7/m^2; Table 4). Even though percent survival dropped by about 37% over these 51 days, the density of urchins on ER #1 was about the same at the time of both counts, before and after the storm. The rate of decline in apparent survival on ER #1 over this 51-day period (9/19 to 11/9/01) was 0.85% per day (Table 7, Fig. 7).

The situation during this period on ER #2 was more complex, and more revealing. A count of urchins made on ER #2 on 10/24/01 (ER #1 was not counted), 12 days before H. Michelle, showed 61% survival of *Diadema* (Table 5). This was a drop of 29% apparent survival over a period of 35 days (9/19 to 10/24), but a gain in density of 0.5/m^2 from the previous count of 0.9/m^2 on 9/19 to 1.4/m^2 on 10/24. The gain in density was a result of the placement of 132 translocated *Diadema* on ER #2 on 9/19 and 9/21/01. The rate of decline of urchins on ER #2 during the 35 days before the storm was 0.8% per day (Table, 7, Fig. 7). The count on 11/9/01 (1.3/m^2), 4 days after the hurricane, showed 48% survival on ER #2 (Table 5), a drop of 13% from the 61% survival of the previous count (0.1/m^2) on 10/24/01, 16 days prior. However, the rate of decline, 0.8% per day, was the same for the 35-day period before (9/19 to 10/24/01) and the 16-day period that included the storm (10/24 to 11/9/01). This indicates that on ER #2, H. Michelle did not cause mortality great enough to increase the daily rate of mortality in the 16

Table 7. ER #1 and #2: percent rate of loss per day (mortality rate) of *Diadema* urchins on each reef at each count.

Date	Total # of days before each count	ER #1 % loss (density) from inception at each count	ER #1 % rate of loss per day (%loss/# days)	ER #2 % loss (density) from inception at each count	ER #2 % rate of loss per day (% loss/# days)
09/05/01	0	0	0	0	0
09/08	3	19	6.33	10	3.33
09/19	14	18	1.29	10	0.71
10/24	49	--	--	39	0.80
11/09	65	55	0.85	52	0.80
12/20	106	55	0.52	56	0.53
02/26/02	174	53	0.31	53	0.31
05/29	267	58	0.22	60	0.23
08/08	338	69	0.20	60	0.18
10/08	399	71	0.18	70	0.18
11/30	452	73	0.16	83	0.18
02/05/03	519	73	0.14	80	0.15

Figure 7. Percent rate of loss per day of total *Diadema* urchins released (daily mortality rate) on each reef at each count.



days that included the storm above the rate during the 35 days before the storm. The last translocation of urchins occurred 12 days before H. Michelle on 10/24, with 21 placed on ER #2, and 34 placed on ER #1.

The placement of urchins on both reefs before H. Michelle (9/19 through 10/24/01) was almost equal, 155 on ER #1 and 153 on ER #2, and the time of release was also similar. The daily rate of mortality on ER #1 (0.85% per day) over the 51-day period between 9/19 and 11/9, which included H. Michelle, was very close to the daily rate of mortality (0.8% per day) that was experienced on ER #2 during the period before (9/19 to 10/24) and the period including the storm (10/24 to 11/9/01). Also, the overall survival rate on 11/9/01 was almost the same on both reefs, 45% on ER #1 and 48 % on ER #2 (Tables 4 and 5).

In summary, the absence of mortality on both reefs from 9/8 to 9/19/01, which included T.S. Gabrielle; the same daily percent rate of loss on ER #2 (0.8%) during the 35-day period before (9/19 to 10/24) and the 16-day period (10/24 to 11/9) that included H. Michelle on ER #2 (0.8%); the close similarity of the daily percent rate of loss on ER #1 and #2 during the 51 days between 9/19 and 11/9/01, which included H. Michelle; and the parallel survival rates (45% and 48%) on both reefs on 11/9 indicate that mortality patterns on both reefs were very similar during the 51 days from 9/19 to 11/30 and that there was no precipitous mortality of urchins on either reef immediately after either storm. The data suggest a gradual loss of urchins over time rather than a rapid loss immediately after H. Michelle on ER #2 and the pattern of loss on both reefs is so similar that if this storm did not cause considerable mortality on ER #2, then it probably didn't cause such mortality on ER #1. This analysis shows that no urchin mortality was caused by T.S. Gabrielle, and indicates, but does not conclusively prove, that precipitous mortality of *Diadema* did not occur as a result of the proximity of H. Michelle.

Storm Mortality Analysis: Time line for counts and storms, 09/08/02 through 11/09/02. G – T.S. Gabrielle, M – H. Michelle, C - count date

09/14 G **11/05 M**
09/08 C ! 09/19 C 10/24 C ! 11/09 C
____!__________!_________!_____________________ !_______!_______!______

Survival percentage (#/m^2 counted/#/m^2 released x 100) and density (#/m^2)
! ! ! ! ! !
! ! ! ! ! !
(1) 80% 1.7/m^2 ! 81% 1.8/m^2 ! 45% 1.7/m^2
(2) 93% 0.9/m^2 ! 93% 0.9/m^2 61% 1.7/m^2 ! 48% 1.3/m^2
! ! ! ! ! !
Daily percent rate of loss (#/m^2 counted/#/m^2 released x 100)/days elapsed
! ! ! ! ! !
(1) ! ----------no loss ----------!--------0.7% per day------------------------------!
(11 days) ! (51 days) ! ! !
(2) ! ----------no loss-----------!--------0.8% per day--------!--0.8% per day----!
! (11 days) ! (35 days) ! (16 days) !
! ! ! ! ! !
Urchins added to reefs
! ! ! ! ! !
(1) 201 11 79 42 34 (total 367) !
(2) 85 27 105 21 (total 238) !

The data above (approximate placement of dates) lays out the time line for counts, percent loss between counts, rate of daily loss from 09/19 to 10/24 to 11/09 (no loss from 09/08 to 09/19), and urchins added to the reefs during the period 09/08 to 11/09/01.

Although these strong storms apparently did not greatly affect *Diadema* populations on these relatively deep (about 25 feet, 7.5 m) patch reefs, the shallow rubble zones on the reef crest absorb much more storm energy and the wave surge rolls and grinds rubble and destroys small urchins that have settled on the scoured rock surfaces. The same wave energy that seems to prepare the rock surface for settlement of post-larval *Diadema* also destroys juveniles that grow and develop in this environment over the late summer and fall months. On 1/3/03, after winter storms, the rubble zone at the north end of Conch reef had few (about 10) healthy *Diadema* in the deeper areas, about 8-10 feet (3 m) deep, along with 3 dead urchins and about 7 with their spines missing. There were no urchins present in the shallow areas, 3-4 feet (1.2 m) deep. A strong sea surge was breaking over the south end of Conch reef at this time.

The initial loss over the first three days, about 19% on ER #1 and 10% on ER #2, occurred before the storms and was most likely a loss of small juveniles, presumably to predation. Small juveniles, however, can hide far under and deeply into coral and rock structures and it is possible that we could not observe all that were present and that the losses after the first three days were not as great as the count indicated. The much greater loss (81% survival) on the more rugged ER #1 compared to the smaller loss (93% survival) on the low relief of ER #2 indicates that either predation was much greater on ER #1 over these three days or that the small urchins were better hidden.

Losses of about 55% (45% survival) on ER #1 and 52% (48% survival) on ER #2 occurred during the first 65 days, and although both storms were included in this period, there was no loss of urchins from T.S. Gabrielle and apparently little, if any, direct loss from H. Michelle.

Survival rates seemed to remain constant at about 45% on both reefs during the fall and winter months. Mortality on ER #1 was apparently a bit greater since 67 additional urchins were translocated to it on 12/20/01 with only 24 urchins translocated to ER #2 on that same day. ER #1 had 43 more urchins added to its population in December 2001 than ER #2. The placement of additional urchins on these reefs during the first four months of the study accounted for the preservation of the density of urchins on the reefs despite the numerical loss of urchins between counts.

Except for the placement of 16 large urchins, test size 3.5-6 cm, on ER #2 on 10/23/02, the 12/20/02 translocations were the last placement of urchins on the experimental reefs for the duration of the study. The survival data from the last 345 days of the study, 2/26/02 to 2/5/03, were most important since few additions of urchins to the reefs affected survival rates during this period. The 16 large urchins released on ER #2 on 10/23/02 were subtracted from the count on 11/30/02 to avoid inflation of the survival calculation during this period. We felt that it was quite likely that all of these 16 large urchins could have easily survived the 38 days between release and the count on 11/30, and to include them would skew the data to indicate a higher survival rate on ER #2 at that count than had actually occurred.

Thus the total number released on ER #2 was recorded as 262 rather than 278 for the 11/30/02 count and the number surviving at this count was recorded as 47 rather than the 63 actually counted. Therefore the density on the 11/30/02 count for ER #2 was 0.5/m^2, and the percent apparent survival at this count was 17%. The 16 urchins released on 10/23/02, however, were included in the final count on 2/5/03 and this accounted for the apparent increase in survival from 17% to 20%, density from $0.5/m^2$ to $0.6/m^2$, percent mortality (as loss of density) from 83% to 80%, and the decrease in the percent loss of urchins per day from 0.18% to 0.15% between the 11/30/02 count and the final count on 02/05/03.

Elimination of these 16 urchins also changes the data for the 11/30/02 count of urchins released on the NE and SE quadrants of ER #2 (Table 8), eliminating 8 from this count on each of these quadrants. The release and count including these 16 urchins released on 10/23/02 is recorded in Table 3, but the corrected values reflecting the elimination of these 16 urchins from the data on this count are recorded in Tables 5, 7, and 8 and on the resulting graphs (Fig. 2-6) as well.

Table 8. ER #2: number of *Diadema* released, cumulative (#Rel), density released ($\#/m^2$), actual number counted, (Cnt), and number present per square meter ($\#/m^2$) on each quadrant at each population evaluation.

Quadrant	NW 20 sq. m				NE 24 sq. m				SW 24 sq. m				SE 20 sq. m			
Date	#Rel	$\#/m^2$	#Cnt	$\#/m^2$	#Rel	$\#/m^2$	#Cnt	$\#/m^2$	#Rel	$\#/m^2$	#Cnt	$\#/m^2$	#Rel	$\#/m^2$	Cnt	$\#/m^2$
09/08/01	15	0.8	14	0.7	25	1.0	18	0.8	25	1.0	20	0.8	20	1.0	27	1.4
09/19	15	0.8	20	1.0	25	1.0	19	0.8	25	1.0	17	0.7	20	1.0	23	1.2
10/24	53	2.7	30	1.5	58	2.4	46	1.9	55	2.3	36	1.5	51	2.6	22	1.1
11/09	57	2.9	32	1.6	65	2.7	37	1.5	58	2.4	17	0.7	58	2.9	32	1.6
12/20	57	2.9	15	0.8	65	2.7	32	1.3	58	2.4	20	0.8	58	2.9	39	2.0
02/26/02	57	2.9	25	1.3	75	3.1	38	1.6	62	2.6	24	1.0	68	3.4	35	1.8
05/29	57	2.9	30	1.5	75	3.1	31	1.3	62	2.6	20	0.8	68	3.4	28	1.4
08/08	57	2.9	19	1.0	75	3.1	31	1.3	62	2.6	28	1.2	68	3.4	25	1.3
10/08	57	2.9	12	0.6	75	3.1	24	1.0	62	2.6	21	0.9	68	3.4	20	1.0
11/30	57	2.9	14	0.7	75	3.1	14	0.6	62	2.6	11	0.5	68	3.4	8	0.5
02/05/03	57	2.9	5	0.3	83	3.5	15	0.6	62	2.6	15	0.6	76	3.8	20	1.0
mean				1.0				1.2				0.9				1.3

Survival rates on both reefs held constant at 45 and 47% over the winter months of December and January, and dropped to 42 and 40% by 05/29/02, about 9 months after the initial translocation. *Diadema* populations on the experimental reefs were not evaluated again until 8/8/02, about 2 months later. Apparent survival dropped to 31% on ER #1 and 40% on ER #2 during this period. Two months later, on 10/8/02, apparent survival had dropped again to 29% on ER # 1 and 30% on ER #2, and about two months later, 11/30/02, apparent survival, about a year after the initial translocation, was 27% on ER #1 and only 17% on ER #2 (excluding the 16 additional urchins that were added to ER #2 on 10/23/02). The last count on 2/5/03 showed a loss of only 4 urchins on ER #1 (119 to 115), which registered as no loss in survival, 27%, based on density of urchins. Survival, based on density, increased on ER #2 from 17% to 20%, despite a numerical loss of 8 urchins, 63 down to 55, due to the placement of the 16 urchins on 10/23/02.

By December 2001, 434 juvenile urchins had been released on ER #1 (reef area of about 96 m^2), which without any subsequent losses would have been a density of $4.5/m^2$. The highest *Diadema* density recorded on ER #1 was $2.1/m^2$ and occurred on 2/26/02. After about 17 months, the urchin density on ER #1 was $1.2/m^2$ (the lowest recorded density) with an apparent survival rate of 27%. The density of urchins on ER #1 at the first count on 9/8/01, was $1.7/m^2$ and $1.2/m^2$ at the last count on 2/5/03. The average density of *Diadema* on ER #1 over the duration of the project was $1.6/m^2$.

A total of 278 urchins (including the 16 released on 10/23/02) were released on ER #2, (reef area of about 88 m^2), which without any subsequent losses would have been a density of $2.98/m^2$. The highest *Diadema* density recorded on ER #2 was $1.4/m^2$ and occurred on 10/24/01 and again on 2/26/02 (45 urchins were released on ER #2 between these counts). After 17 months the urchin density on ER #2 was $0.6/m^2$ with an apparent survival rate of 20%. The average density of *Diadema* on ER #2 over the duration of the project was $1.0/m^2$.

The total area of reef structure of both experimental reefs was 184 m^2. By number, 61% (434) of the 712 urchins were placed on ER #1 and 39 % (278) were placed on ER #2. Numerically, by 2/5/03 ER #1 lost 74% of the urchins placed on it, and ER # 2 lost 80%. The potential density of the release of 712 urchins combined for both reefs was $3.9/m^2$ and at the end of the study, the surviving density for both reefs combined was $0.9/m^2$. Despite considerable differences in numbers of urchins placed on each reef, a total potential density of $4.5/m^2$ on ER #1 and $3.2/m^2$ on ER #2, the average density of *Diadema* on both experimental reefs over the 17-month term of the project was $1.6/m^2$ on ER #1 and $1.0/m^2$ on ER #2, a difference of $0.6/m^2$. The total loss of density on ER #1 ($4.5/m^2$ down to $1.2/m^2$) over the course of the study was $3.3/m^2$ compared to the loss of $2.6/m^2$ ($3.2/m^2$ down to $0.6/m^2$) on ER #2, a greater loss of potential density of $0.7/m^2$ on ER #1 than on ER #2.

A difference of $0.6/m^2$ separated the total density of urchins on ER #1 ($1.2/m^2$), from ER #2 ($0.6/m^2$) 17 months after initial placement of urchins on these reefs. The overall urchin density was greater on ER #1 than on ER #2 at each count (Fig. 6), but the percent apparent survival of urchins on each reef was very similar until the 8/8/02 count (Fig. 5). After excluding the 16 urchins added to ER #2 on 10/23/02 for the 11/30/02 count, ER #2 had a 58% decline in urchin density from $1.2/m^2$ down to $0.5/m^2$, between 8/8/02 and 11/30/02. ER #1, however, with a density loss of $1.4/m^2$ down to $1.2/m^2$, a decline of only 14%, did not experience a similar loss over the same period. Predation seems the most likely cause for the precipitous decline on ER #2; perhaps the relative scarcity of complex reef structure on ER #2 made the urchins more available to predators on this reef.

Overall, however, the rate of loss of urchins on both reefs was similar. The daily rate of loss of percent density of urchins on both reefs was calculated by dividing the percent loss (mortality) of urchins (100 – (#/m^2 counted / #m^2 released x 100) on each experimental reef at the time of each count by the number days elapsed since the first translocation of urchins. This provided the daily rate of loss from the beginning of the project of the percent mortality at the time of each count (Table 7 and Fig. 7).

The initial rapid loss of urchins is evidenced in the high daily rate of loss over the first 3 days after the first translocation. Although survival rates were relatively high over these 3 days, 81% on reef # 1 and 90% on reef # 2, the short time period of 3 days produced a high daily rate of loss, 6.3% per day on reef # 1 and 3.3% per day on reef # 2. It may be that the small juveniles that were translocated succumbed rapidly to predation or that many of these smallest urchins were not detected in the complex reef structures on the first count. Interestingly, despite the structural and areal differences in the two reefs; the differences in the numbers of urchins released and counted on these reefs; and the varying number days between counts, after the initial period of 65 days; the daily rate of percent mortality on each reef is very close from Nov., 2001 to Feb. 2003 (Table 7). And this daily rate of loss was relatively stable on both reefs at about 0.2% from 5/29/02 through 11/30/02. The average percent rate of loss per day from the total number of urchins that were placed on both reefs from 2/26/02 through 11/30/02, 278 days, was 0.21% on ER #1 and 0.22% on ER #2, and the average loss of density from 2/26/02 to 11/30/02 was 0.9/m^2 on both reefs, a daily rate of density loss of 0.003/m^2 per day on both reefs. In the 67-day period between the last two counts, 11/30/02 and 2/5/03, ER #2 continued to lose urchin density (8 urchins, 0.09/m^2) more rapidly than ER #1 (4 urchins, 0.04/m^2).

Mortality due to predation is assumed to the major cause of loss of urchins on the experimental reefs. However, it is possible that some urchins moved off the reefs onto other nearby reefs. A few large urchins were observed on CR #3 during a night dive on 8/28/02, but such movement would have had to occur over 40 to 50 feet (12 to 15 meters) of seagrass bed that separated ER #1 from CR #3, so we consider movement of urchins off the experimental reefs as possible, but unlikely.

Our primary interest in this project was to investigate survival of the translocated *Diadema* on the experimental reefs and the effect that these urchins may have on the benthic ecology of these reefs. Growth rates, movement of urchins on the reefs, preference for particular microhabitats, and distribution of urchins on the reefs were also of considerable interest, but the frequent monitoring and detailed experimental design required to fully explore these considerations were beyond the scope of this project. Analysis of the survival and/or movement of translocated *Diadema* within each of the 4-m^2 sectors was not possible. However, analysis of the numbers of urchins released and the numbers counted in each quadrant of the experimental reefs at each population evaluation did yield interesting results.

Changes in urchin populations in each quadrant of each reef would be due, in varying measure, to differential survival and/or movement of urchins between quadrants. The boundary line between quadrants often ran through coral reef structures so, in some areas, urchins moving from one side of a coral head or complex coral structure to the other would move from one quadrant to another with relatively little actual linear movement. However, despite the inherent vagaries of urchin populations in the quadrants, some understanding of the distribution of urchins on the reefs can be gleaned from this data.

Movement of an urchin from one quadrant to another registered as a loss to one quadrant and a gain to another. A gain in population would result from either movement into that quadrant or settlement of new recruits in that area. After the first two months, the presence of new recruits on any area of the experimental reefs would have been quite obvious, and newly settled *Diadema* would not have been noticeable on the reef during the first month. In a study of settlement of *Diadema* off Curacao, Bak (1985) reported growth of newly settled *Diadema* at about 3-6 mm in a two-week period, and Forcucci (1994) estimated an early growth rate of about 7 mm per month for urchins on Florida Keys reefs. We would not have noticed newly settled *Diadema* until they had attained a test size of at least 5 mm, probably a month or so after settlement and such small urchins would have been quickly identified as recent recruits. We are reasonably certain that few *Diadema* settled and survived on these reefs until early fall of 2002.

Increases in populations on any quadrant are assumed due to movement to more “desirable” environments with better shelter and/or stronger algal growth. Decreases in populations may be due to urchin movement out of a particular quadrant or loss from predation (or other cause of mortality) within that quadrant. A study using spine tags to track individual urchins by Carpenter (1984) demonstrated that *Diadema* returned with remarkable fidelity to the same daytime shelter and that the urchins avoided grazing on the same areas that were foraged the previous night.

Tables 6 and 8 list the cumulative numbers of *Diadema* released in each quadrant of ER #1 (Table 6) and ER #2 (Table 8) and the numbers of urchins observed in each of the quadrants on each reef at each count (population evaluation). Also listed in these tables are the density (#/m^2) of urchins released (cumulative) in each quadrant and the density (#/m^2) of urchins on the reef area of each quadrant at each count.

This data from each quadrant of each experimental reef is expressed as line graphs of the changes in density on each quadrant at each count. Figures 7 (above) and 8 show changes in density of urchin populations on each quadrant of ER #1 and ER #2. These line graphs compare the density of urchins cumulatively released on each quadrant with the density of urchins present on each quadrant at each population evaluation. Figures 9 and 10 show the changes in the percent density of urchin populations, (#/m^2 counted/#/m^2 released x 100) on each quadrant of ER #1 and ER #2, and on the total reef area. These line graphs compare increases and/or decreases in density of urchin populations relative to the density of the total number of urchins released on each experimental reef and on each quadrant of each reef at the time of each population evaluation. They illustrate relative survival and/or accumulation of urchins in these areas.

Figure 8. Reef # 1: Density of Diadema urchins (#/sq. m) cumulative total released (R) and number counted (C) on each quadrant at each count.

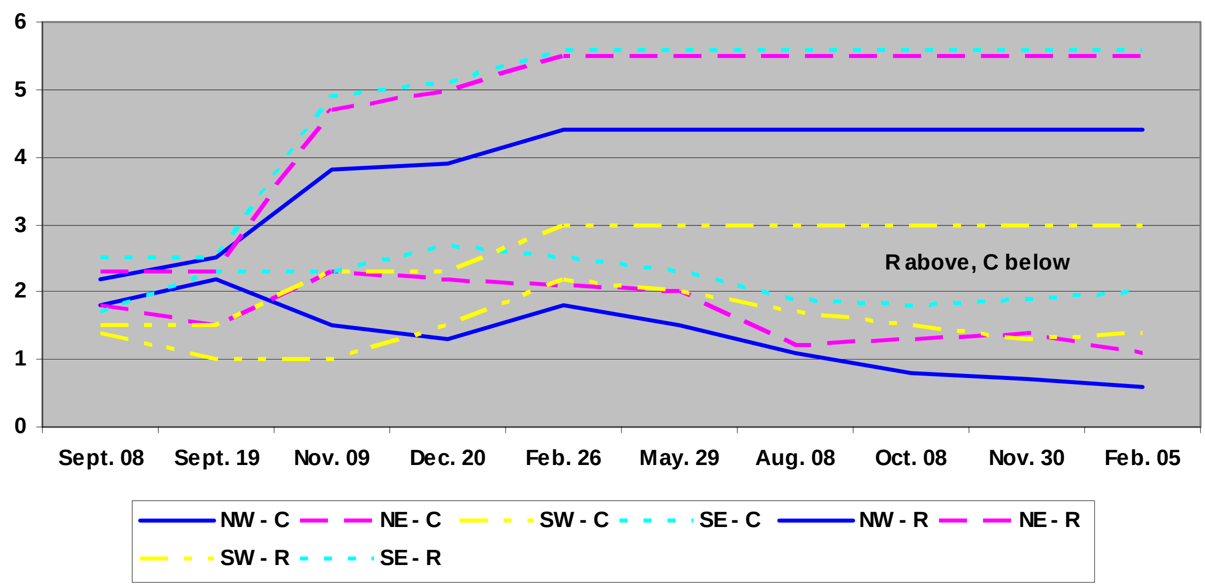


Figure 9. Reef # 2: Density of Diadema urchins (#/sq. m) released (R) and number counted (C) on each quadrant at each count.

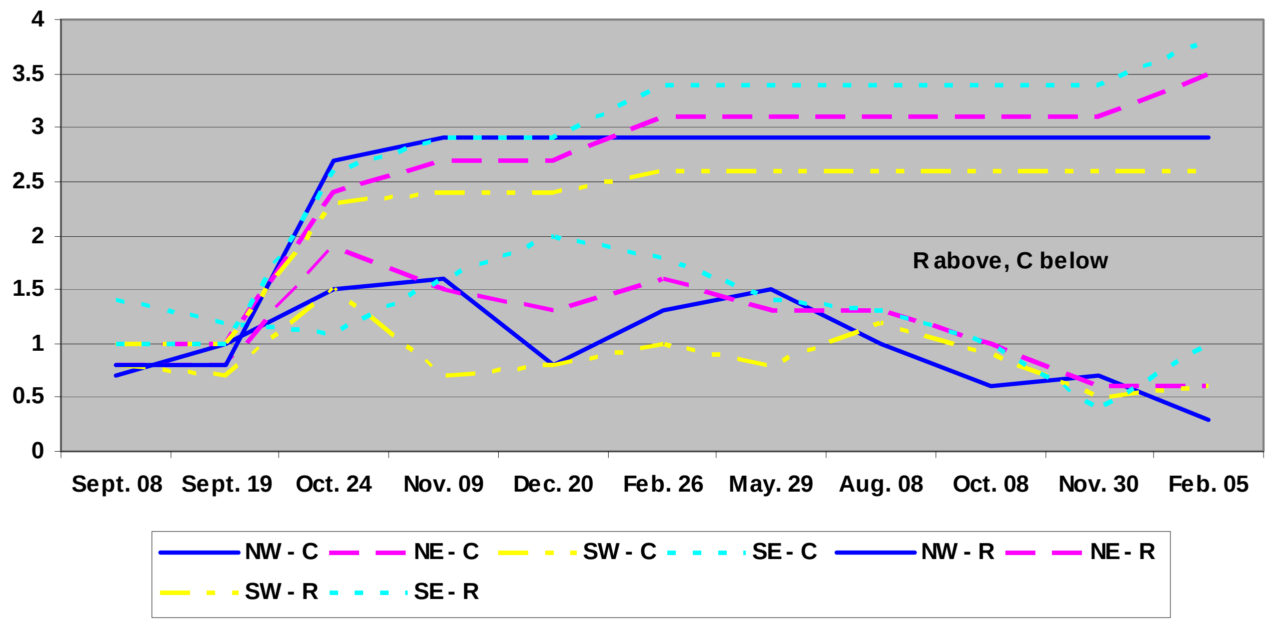
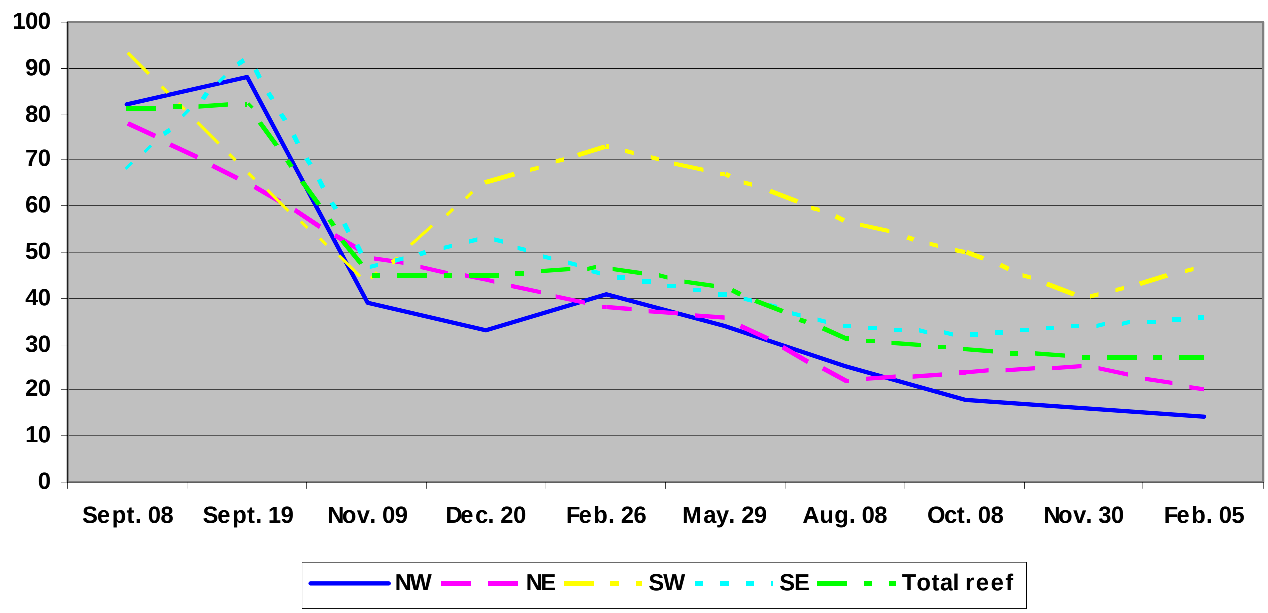


Figure 10. Reef # 1: Percent change in density of Diadema (#/sq. m counted / #/sq. m released on quadrant and on the total reef area at each count.



Without marking individual urchins, it is not possible to know definitively whether a loss of urchins in a quadrant between counts was due primarily to movement or to mortality. However, an increase in the number of urchins in a quadrant in the absence of release of additional urchins in that quadrant must be due to movement of urchins into it. Also, an increase in urchin density in one quadrant over the same period as a decline in density in another quadrant may be due to movement rather than differential mortality. A decline in density of urchins in a quadrant that was markedly less than declines in other quadrants and less than the reef-wide decline, may be due to a movement of urchins into that quadrant, although significantly less mortality in that quadrant than in others cannot be discounted.

Experimental Reef #1

The data on placement and count of urchins in each quadrant of ER #1 over the course of the project is summarized in Tables 4 and 6 and in Figures 8 and 10. There was evidence of some movement of *Diadema* on ER #1 after initial placement. On ER #1 the density of urchins in the SE quadrant increased from 1.7/m^2 to 2.2/m^2 (0.5/m^2, an increase from 68 to 92) between 9/8 and 9/19/01 without the addition of new urchins. The density of urchins on the SW quadrant declined by 0.4/m^2 and the density on the NE quadrant declined by 0.3/m^2 without addition of new urchins, so it seems likely that urchins moved from the NE and SW quadrants into the SE (which has a border common to both NE and SW quadrants) over the 11 days between counts. The increase in urchin density of 0.4/m^2 in the NW quadrant was likely due to the placement of 11 urchins in this quadrant on 9/17/01.

The SE quadrant of ER #1 contains large and complex boulder coral formations, *Montastraea cavernosa*, and covers a relatively small area, 20 m^2. It would be expected that this complex reef structure would attract and contain a higher density of *Diadema* because of the shelter that these structures offer. The SW quadrant of ER #1 also contains large boulder coral structures and was a bit larger in total reef area, 24 m^2, and the NE quadrant, with the same area as the SE quadrant, also contained some large coral structure. The NW quadrant, with lower and less complex coral structure, also covered 24 m^2.

Placement density of urchins in the quadrants of ER #1 (5.6/m^2 SE, 5.5/m^2 NE, 4.4/m^2 NW, and 3.0/m^2 SW; Fig. 7) varied considerably (Table 4, Fig. 8). The two quadrants with the highest placement densities, NE and SE, had the highest average densities, NE 1.7/m^2 and SE 2.1/m^2, over the course of the project. The quadrant with the lowest placement density, NW, had the lowest density, 0.6/m^2, only about half the density of the other three quadrants at the last count on 2/5/03. Evidently, urchins on the NW quadrant experienced a higher mortality rate or moved into the more rugged nearby quadrants. The percent apparent survival (47% and 36%) and the final density (1.4/m^2 and 2.0/m^2) were greatest in the SW and SE quadrants at the end of 17 months. These were the quadrants on ER #1 with high and rugged coral growth.

The percent urchin density (Fig. 10) declined rapidly in the SW quadrant from initial placement of urchins on 9/4/01 (93% on 9/8/01) through 11/9/01 (43%), but then rapidly increased back up to 73% on 2/26/02. Despite receiving the lowest number of translocated urchins (71, 3.0/m^2), the percent density (47% after 17 months, Fig. 10) in the SW quadrant remained considerably higher than the other quadrants and higher than the total density on the reef. Percent urchin density in the SE quadrant was also greater than that on the total reef while quadrants NE and NW were below the density on the total reef (Fig. 10).

Although some movement into the SE and especially the SW quadrants seems to have occurred (Fig. 10), in general, a gradual and similar decline in urchin densities in the SW and NW quadrants occurred while urchin densities on the NE and SE quadrants did not decline and even slightly increased from 8/8 to 11/30/02 (Fig. 8 and 10). Between 11/30/02 and 2/5/03, however, density in the SW quadrant increased while density in the NE quadrant declined by about the same amount. A departure from this picture of gradual decline or little change in the density of urchins on each quadrant after 2/26/02 is evident in a marked decline in density in the NE quadrant that occurred between 5/29 (2.2/m^2) and 8/8/02 (1.2/m^2). This quadrant contains the sheltered site within a large coral structure that was occupied by both large Atlantic burrfish and this quadrant may have been a focus for predation during that time prior to the removal of the second one on 9/28/02.

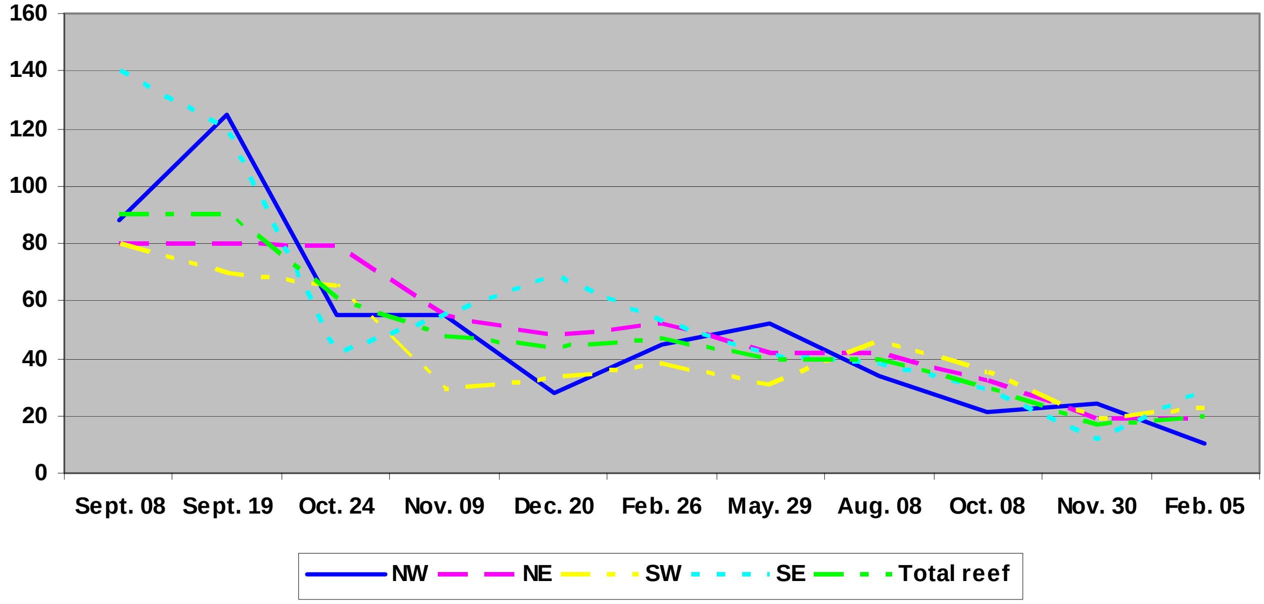
In general, the pattern of distribution and changes in density of urchins on ER #1 over the course of the study showed a tendency for accumulation of urchins in the SW and SE quadrants, especially in the SW quadrant, and a greater loss or movement out of the NW and to a lesser degree the NE quadrants (Fig. 10). Urchins are probably attracted to the high relief and rugged coral formations of the SW and SE quadrants, and/or have better survival in these areas.

Experimental Reef #2

Data on placement and counts of urchins on each quadrant of ER #2 over the course of the project is summarized in Tables 5 and 8 and in Fig. 9 and 11. ER #2 is more homogenous in reef structure than ER #1. There are no large, complex coral structures and the coral structures that are present have low relief. Considerably fewer *Diadema* were translocated to ER #2 and they were distributed more evenly over the quadrants (2.9/m^2 NW, 3.5/m^2 NE, 2.6/m^2 SW, and 3.8/m^2 SE) than on ER #1. Density of urchins was always less on ER #2 than on ER #1 (Fig. 6) with the closest density, 1.4/m^2 on ER #1 and 1.2/m^2 on ER #2 occurring on 8/8/02 (Tables 4 and 5

Within the first 15 days or so there was strong movement of the translocated urchins into the NW and, in the first 3 days, especially into the SE quadrant of ER #2. Although relatively few urchins were released on this reef (85) in the first translocation on 9/4 and 9/5/01, and no further urchins were placed on the reef until 9/19/01, density in the SE quadrant increased to 140% of the density at release on 9/8/01 (3 days after release), and then declined to 120% on 9/19/01 (14 days after release). The population in the NW quadrant was 88% of the release density on 9/8/01, but then climbed to 120% of the release density on 9/19. In contrast, the population densities of the NE and SW quadrants were relatively static at 80% and 70% of the release densities over the period from 9/8 to 9/19/01. In actual numbers, these figures represent a gain of 7 urchins to the SE quadrant and a loss of 1 urchin to the NW quadrant between 9/5 and 9/8/01 and a loss of 5 urchins to the SE quadrant and a gain of 6 urchins to the NW quadrant between 9/8 and 9/19/01. Some urchins did move, however, from the NE and SW quadrants to the NW and SW quadrants very soon after translocation.

Figure 11. Reef # 2: Percent change in density of *Diadema* (#/sq. m counted / #/sq. m released) on each quadrant and on the total reef area at each count.



In general, after 10/24/01, urchin density declined gradually at a similar rate in all quadrants during the rest of the study. A notable exception, however, was a rapid loss of density in the NW quadrant (1.6/m^2 to 0.8m^2) from 11/9 to 12/20/01. The NE and SW quadrants also lost density during this period. In contrast, the SE quadrant gained density from 10/24 to 12/20/01 (1.1/m^2 to 2.0/m^2), an indication that some movement toward the SE quadrant occurred.

The SE quadrant had by far the greatest number of urchins (27) and greatest density (1.4/m^2) at the first count on 9/8/01 and the least number of urchins (8) and lowest density (0.4/m^2) at the count on 11/30/02. However, on the final count on 2/5/03, the number of urchins on the SE quadrant rose from 8 to 20, a gain in density from 0.5/m^2 to 1.0/m^2. The addition of 16 urchins to this reef on 10/23/02 as well as movement to this quadrant probably accounted for this gain. After 2/26/02 the density of urchins on all quadrants of ER #2 varied from 1.8/m^2 in the SE quadrant to 1.0/m^2 in the SW quadrant, but on 11/30/02, 278 days later, the distribution of urchins over the reef was almost equal in all quadrants, from the highest in the NW quadrant of 0.7/m^2 to the lowest in the SE quadrant of 0.4/m^2. Between 11/30/02 and 2/5/03 there was a marked decline in density in the NW quadrant (0.7/m^2 to 0.3/m^2) and an increase in density (0.5/m^2 to 1.0/m^2) in the SW quadrant. The decline was even and gradual in the NE and SE quadrants and more variable with opposite peaks and dips in the NW and SW quadrants (Fig. 9). The average density of urchins on each quadrant over the course of the project was very similar (NW 1.0/m^2, NE 1.2/m^2, SW 0.9/m^2, and SE 1.3/m^2). Thus in general, the population of *Diadema* on ER #2 maintained a variable, but generally homogeneous distribution over the reef over the last 12 months of the project. The lack of high relief and rugged coral formations on this reef probably contributed to this pattern of distribution.

Diadema *Recruitment*
There has been speculation on the role, if any, that a population of adult *Diadema* may have in stimulating settlement and/or survival of post-larval *Diadema* in the area of the adults through preparation of the substrate (including stimulation of the growth of coralline algae) and/or release of pheromones (perhaps stimulation to begin metamorphosis). In addition, adults may directly aid in the survival of newly settled juveniles through protection under the spines of the adults. Three or four small, apparently newly settled *Diadema* urchins were observed on ER #1 during the course of the study, and on 11/30/02 we found 6 new juveniles on ER #1 and 4 on ER #2. On 2/5/03 there were 3 small juveniles on ER #1 and 1 on ER #2; no juveniles were observed on the control reefs. They were not found in the immediate presence of adults and it was not obvious that the presence of the now adult *Diadema* on these reefs influenced settlement in any way, but the presence of these juveniles is suggestive of an adult influence. These juveniles were included in the counts on those dates.

It has been noted that *Diadema* larvae prefer to settle in areas cleared of filamentous algae (Bak 1985; Lessios 1995) and this may be the main reason why settlement occurs in the reef crest rubble zones where the coral rock substrate is cleaned of algae by frequent movement and abrasion caused by high sea states. The rocky substrates of these shallow rubble areas and reef areas with dense populations of *Diadema* are both relatively clear of algal growth. Lessios (1995) reported on extensive research conducted with *Diadema* and other urchins that occupy similar reef environments, in particular *Echinometra viridis*, which competes with *D. antillarum* for food and substrate. Lessios' research showed that high densities of *E. viridis*, which graze the substrate more intensively than *Diadema*, produced areas with greater rates of *Diadema* recruitment than areas with both *E. viridis* and *D. antillarum* and *D. antillarum* alone. Areas with only *D. antillarum*, however, had greater recruitment than areas with no urchin populations. Lessios (1995) concluded that lack of recruitment months after the 1983-84 die-off was due to extreme paucity of *Diadema* larvae in the waters of the Caribbean.

Our study indicates that on Florida reefs, the presence of adult *Diadema* is, or should be, helpful to the recruitment of juvenile *Diadema*. Many juveniles settle on the shallow rubble areas of Conch and Pickles Reefs during late summer and fall of each year. There is an absence, or extreme dearth, of recruits, however, on the deeper patch reefs where our study took place only a mile or so inshore from these reefs. If some larvae nearing settlement are present in the waters of Conch and Pickles Reefs, which they must be, then there should also be some larvae present that could, and probably do, settle on nearby reefs as well. Small juveniles 1 to 2.5 cm test diameter, translocated to these reefs survived in large numbers for many days after translocation, thus there is nothing intrinsic in the environment of these patch reefs that would prevent significant survival of juvenile *Diadema*, at least not after a test size of 1.5 to 2 cm is attained. In November, 2002, about one year after translocation and maintenance of an increased population level of *Diadema*, we observed a number of juvenile *Diadema* that had settled on the experimental reefs. The number of new juveniles was not great, 10 to 12, roughly about $0.07/m^2$, but this demonstrates that *Diadema* post-larvae will settle and survive on Florida reefs where populations of adults are present. However, according to the survival data in our study, settlement and survival of about 1.2 *Diadema* urchins per year on each square meter of reef area is required to maintain a population of about 1 to 2 urchins/m^2 on the patch reefs of our study. Mortality immediately after settlement is probably very high, so settlement of post-larval *Diadema* in numbers far greater than 1.2/m^2 is no doubt necessary to secure survival of 1.2 urchins/m^2. We feel that the scarcity of *Diadema* recruits on Florida Keys patch reefs is due to both paucity of larvae in the water mass and a lack of proper substrate and/or settlement stimulus on reefs without an adult population. In all probability, however, given the occurrence of scattered individuals and small groups of urchins in various locations on Keys reefs, the scarcity of late stage larvae in the water is a more significant factor in the failure of *Diadema* to repopulate Florida reefs than the lack of prepared substrate.

An adult female *Diadema* can produce 10 million eggs every month (Levitan 1988) and Tom Capo (personal communication) in rearing experimentation with *Diadema* reports the fecundity of some individuals at 15 to 20 million eggs per spawn. When *Diadema* were present on most reefs of the Caribbean, Florida, and the Bahamas at densities from about 1/m^2 up to perhaps 20/m^2, the larval load of *Diadema* in these waters must have been immense. (One can only wonder at the changes that must have occurred in the planktonic ecology of these waters upon the abrupt elimination of this immense component of the zooplankton population.) Despite such extraordinary fecundity, small populations of adults scattered widely over reef areas are not capable of producing large numbers of larvae. This is because *Diadema* are sessile spawners; males and females release gametes into the water without physical contact and without regard to proximity of individuals. When males and females are more than about a meter apart, fertilization is severely compromised and few viable larvae result. Also, the scarcity of large adults greatly reduces the fecundity of populations (Levitan 1991).

Small populations and widely spaced individuals are not able to produce the numbers of larvae necessary for recovery of populations to pre-die-off levels. Natural recovery of dense *Diadema* populations will depend on the chance coalescence of many factors that are favorable to successful settlement and survival of larvae. It will be necessary for these factors to merge frequently in order to maintain established populations.

Growth

Growth rates of *Diadema* under natural conditions depend on many factors including genetics, temperature, water quality, reef structure, and quantity and quality of benthic algal communities. Accurate determination of growth rates of *Diadema* under well defined natural conditions would require tagging of a significant number of individual urchins, probably at least 30, and frequently and accurately measuring the test diameter of each urchin over an extended period, at least 6 months to a year. Repeating these experiments under differing conditions of depth, benthos, and seasonality would also be necessary to characterize variability of growth rate potential for this species in various locations.

Although we were not able to conduct such detailed experimentation on growth, we did make estimates of the size range of the *Diadema* collected and translocated to the experimental reefs. Table 2 lists the size ranges of the collected urchins, 249 (34%) were in the small range (1-2.5 cm), 306 (41%) were in the medium range (2.6-4.9 cm), and 186 (25%) were in the large range (4.5-6 or more cm). This collection data illustrates that by far the large majority of the translocated urchins were young juveniles of small test diameter since 75% had a test diameter of less than 4 cm. Very few were larger than 4.5 to 5 cm. We noticed during the 12/20/01 population evaluation that very few, if any, of the urchins observed were in what we had defined as the small and medium size ranges. Although it is possible that smaller sized urchins sustained the greatest mortality due to predation, it is unlikely that all the smallest urchins would have been lost and only the larger ones survived during the first three to four months. Survival rates on 12/20/01 were 46% on ER #1 and 45% on ER #2, so many urchins in the small and medium size ranges must have survived to that point. It is likely that many small urchins in the 2 cm test size range grew to test diameters of 3.5-4 cm within the first 4 months. Also, the benthic survey by NURC (next chapter) showed that by far the greatest test size range of *Diadema* found on the experimental reefs in September 2001 were in the 4.0-4.9 cm range. So, in general, *Diadema* on Upper Keys offshore patch reefs appear to attain a test size of 4-5 cm within about one year. Forcucci (1994) reported a growth rate of over 4 mm per month for juveniles with test diameters up to 24.0 mm, and our observations roughly agree with this rate for urchins in the 2.0-4.0 cm test diameter range. In general, *Diadema* achieve a test diameter of about 3-4 cm within the first year and about 4-5 cm in the second year, and a low estimate of longevity is 4 years with a test diameter of about 10 cm (Ogden and Carpenter 1987).

Discussion

There were four specific biological restoration objectives in this project. We feel we have succeeded in attaining these objectives to a large degree during the conduct of this project. Each of these objectives is listed below with a brief comment on what this study has revealed on these topics.

1. Determine if *Diadema* survive transplantation and the size that exhibits the best survival rate after transplantation.

Diadema clearly survive transplantation. The initial survival rates of 80 to 90 percent over the first few weeks after translocation and continued survival at levels of about $1.0/m^2$ over the entire year of the project demonstrate that adequate survival of translocated *Diadema* is attainable. We were not able to definitively determine the best size for translocation, but the indications are that larger urchins, test size greater than 2 cm, survive better than smaller urchins.

2. Estimate the survival and growth rates of transplanted *Diadema*.

Survival rates on each experimental reef and on each quadrant of each reef were carefully analyzed. The initial high loss rates (presumably mortality) over the first two to three months leveled off at about 50% and, over the last 12 months of the study, survival dropped to about 25%. Densities, however, were maintained at about $1\text{-}2/m^2$ on both experimental reefs throughout the sturdy. The daily rate of percent reduction in density of urchins on both reefs after the first two months was the same. Over the 9-month period, 2/26/02 to 11/30/02, the density of urchins declined $0.9/m^2$ on both experimental reefs, a daily rate of loss of density of about 0.0032 urchins/m^2 on both reefs. To maintain a population of *Diadema* at a density of about $1/m^2$ on a reef area, a recruitment rate that would support survival of about 1.17 urchins/m^2 of reef area per year would be required.

It is tempting to speculate that translocation of *Diadema* on Florida Keys reefs, especially larger urchins, should be targeted at densities of about $2/m^2$. Densities greater than $2/m^2$ may experience undue loss and densities less than $1/m^2$ may be too few to establish persistent and biologically effective populations. This speculation is based more on intuition and experience than analysis of data. Also, Lessios (1995) reported that the average density on all reefs censused in the San Blas area of Panama before the die-off was close to $1.0/m^2$. However, population densities much greater than $1/m^2$ were not uncommon in the Caribbean. Bak (1985) reported that densities of *Diadema* along the southwest coast of Curacao were $4\text{-}12/m^2$ during the period 1975 to 1983. Although populations much greater than $1.0/m^2$ have been reported, healthy populations over broad areas containing varied types of reef structure and hard bottom in the Florida Keys may have a "climax density" of about $1.0/m^2$. The various types of reef structure present in Florida Keys reefs, various exposures to predation, and perhaps most important, varied incidence of recruitment may greatly affect the density of urchins on specific reef areas in various locations. Research on the response of urchin populations translocated to various reef types and locations is needed.

Estimates of growth rates observed in this study indicate that only about 4-6 months are required for juveniles (1.5 to about 2.0 cm test diameter) to attain a small adult size of 3-4 cm test diameter.

3. Determine the distribution patterns that *Diadema* develop on test reefs.

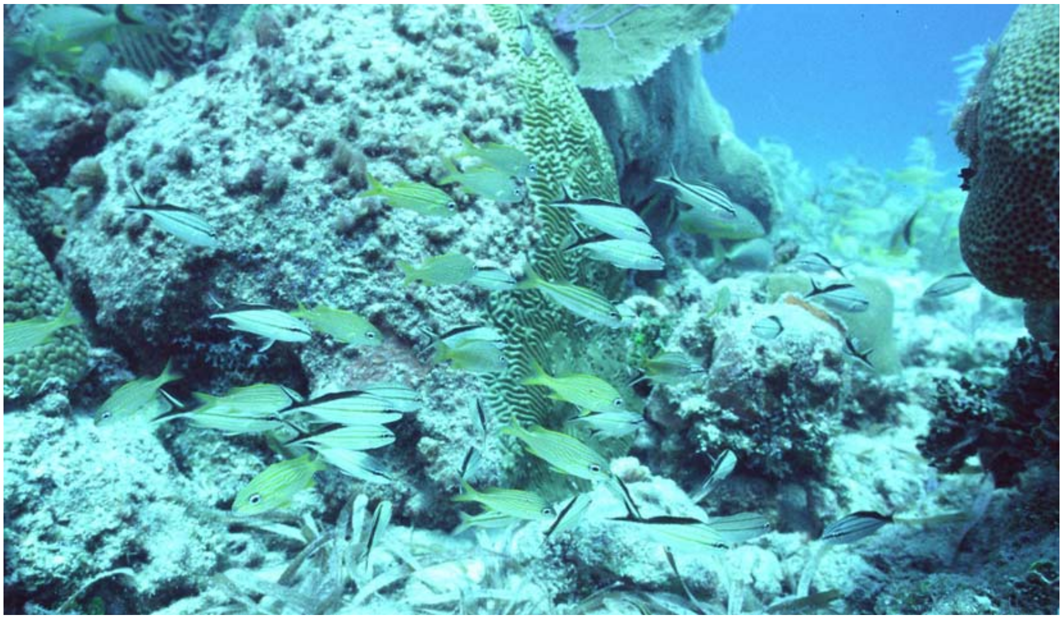
The distribution patterns of *Diadema* on these patch reefs were indicated by data on the density of urchins in the four quadrants of each experimental reef. In general, although there was movement of urchins from quadrant to quadrant, and indications of concentration in quadrants with high and complex coral formations, for the most part, urchins remained relatively evenly distributed over all the quadrants of each experimental reef.

4. Compare and contrast general reef condition and community level changes, including coral recruitment and growth, on the manipulated and reference reefs over time.

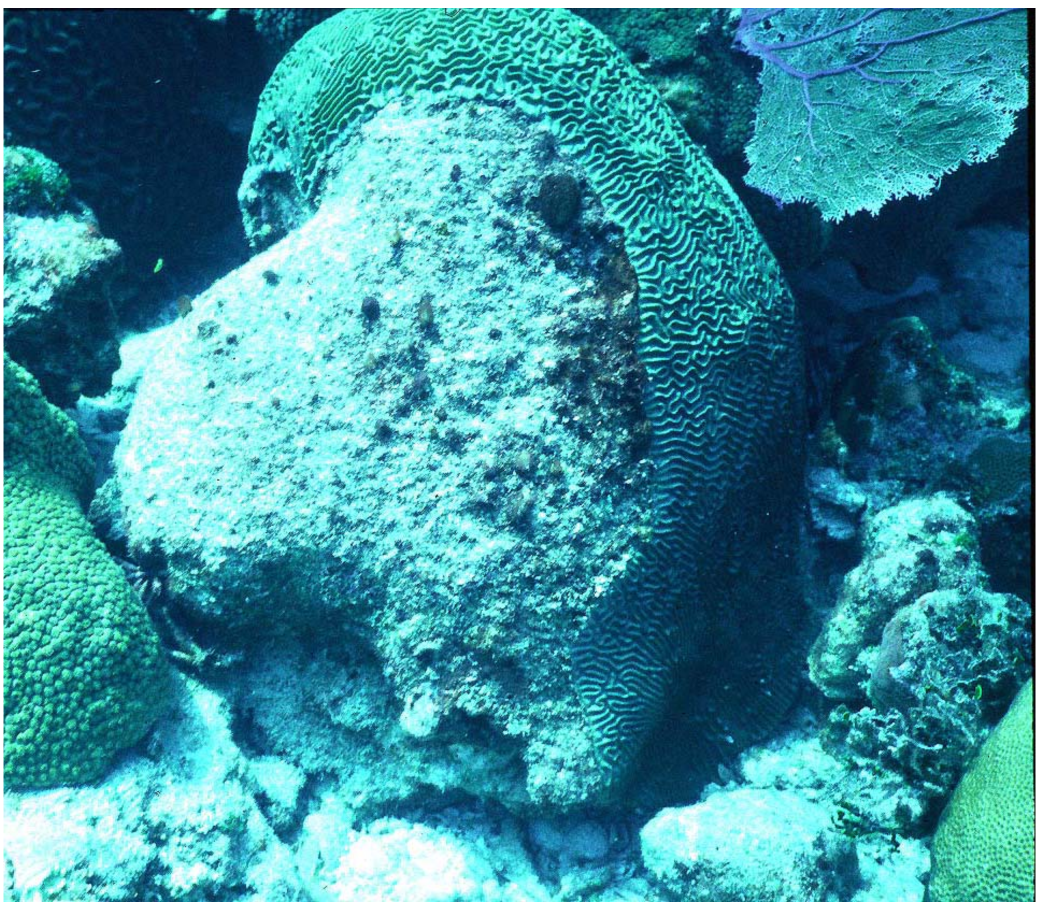
The before and after benthic assessments by NURC (next chapter) demonstrated that, among other positive changes on the experimental reefs, algal cover was markedly decreased, coralline algal cover markedly increased, stony coral cover increased, and the density of juvenile corals increased significantly over that of the control reefs.

Coral head on ER #1 in September 2001 before translocation of *Diadema*. Note the heavy algal growths.

Same coral head as above in August 2002. Note great reduction in algal growth.

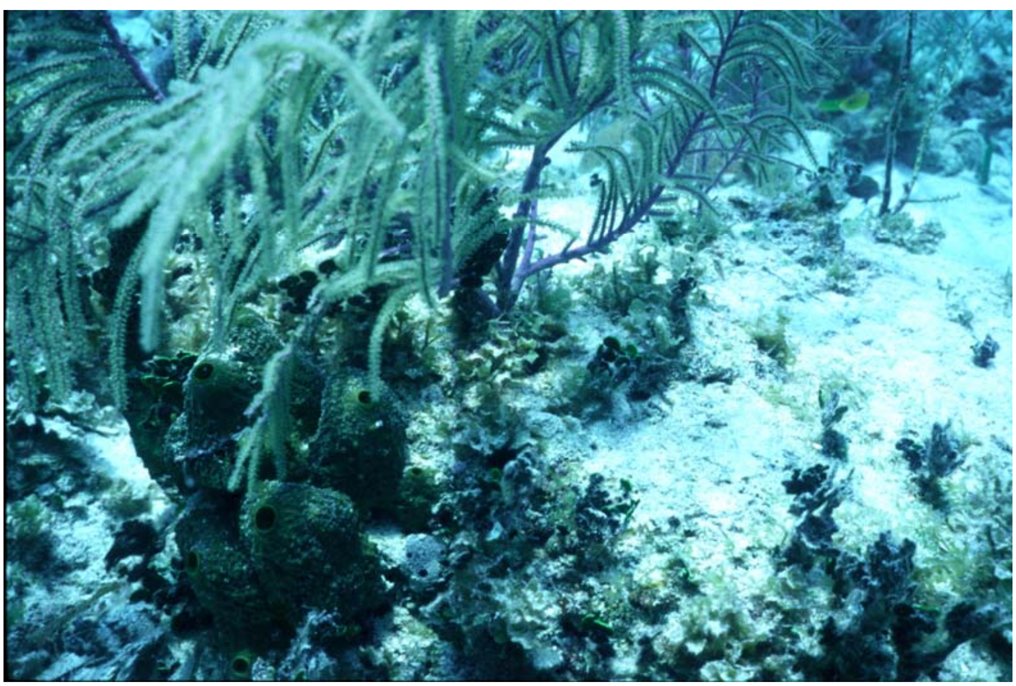


Dying coral head on ER #1 in September 2001. Note extent of erosion of living coral tissue and growth of algae on rock surfaces.



Same coral head as above on August 2002. Note removal of algae on rock surfaces and regeneration of coral tissue on upper section of formation.

Typical algal fouling on rock on ER #1 before translocation of urchins.



Typical rock reef area on ER #1 in August 2002 one year after urchin translocation.

Diadema are relatively immobile during the day and move about as they feed at night. They may return to a particular sheltered area during the day or may simply find an adequate shelter as dawn approaches. At the beginning of the project we observed a particular juvenile that had apparently settled naturally and that occupied a specific small cavity in a rock structure on the SE quadrant of ER #1over a period of several months. This indicates that at least juveniles tend to remain in the same area and occupy the same shelter during the day. Large adults probably have a greater range and may occupy various sheltered areas during the day.

In this study, once *Diadema* attained an adult size of about a 4 cm test diameter and above, mortality rates declined to slightly less than 1.0 urchin/m^2/year, a rate of about 0.0025 urchin/m^2/day.

A major concern on repopulation of *Diadema* on Florida reefs is the potential for the return of the presumed pathogen that decimated populations of these urchins in 1983-84. This is a real concern, especially since there was a secondary mortality of *Diadema* in 1990-01 (Forcucci 1994). The mortality caused by this epizootic is rapid and affects almost all *Diadema* within a very broad area. The mortality we observed on the experimental reefs during this study was gradual and persistent, but affected only a relatively small number of urchins at any one time. We also never observed the disintegration of urchins leaving a mass of disarticulated tests and spines, thus disease apparently did not cause urchin mortality during our study.

Predation was evidently the major cause of mortality of urchins on the experimental reefs. We directly observed predation on the urchins by the Atlantic burrfish, *Chilomycterus atinga*, and other predators such as triggerfish, hogfish, permit, grunts, spiny lobsters, and spider crabs may have also actively preyed on the urchins, especially on small juveniles, but active predation by other predators was not observed during our study. Such predators once accustomed to feeding on *Diadema* and upon finding a relatively dense population, may quickly remove a significant number of urchins before moving on to other areas. Without consistent recruitment adequate to maintain an effective population, these small isolated populations dwindle in number over a period of months to years. Populations of *Diadema* that occur in areas with some protection from predators, such as shallow protected areas or rugged and complex reef areas may better resist predation and persist in numbers over a longer period. Also, very low levels of recruitment would be more effective in maintaining populations in such areas.

Restoration

The importance of healthy populations of *Diadema* to the coral reefs of the Florida Keys cannot be overstated. The following summation by Ogden and Carpenter (1987) based on over 20 years of experiments and observations is a strong testimony to the need for restoration of this species:

"Through direct effects on algal communities or indirect effects on other benthic reef organisms, grazing by *Diadema* is a major factor controlling the community structure of coral reefs. ….. perhaps no other single species in the coral reef environment has such profound effects on the other organisms composing the reef community."

The major underlying purpose of this study was to explore the results and possibilities of restoration of *Diadema* to reefs of the Florida Keys. As noted in the literature for Caribbean reefs, and as demonstrated in this study, the benthic ecology of coral reefs shifts away from dominance by macroalgae back toward dominance of coral growth relatively quickly after populations of *Diadema antillarum* at densities of about $1/m^2$ are present on the reefs. It is obvious that the reefs of the Florida Keys would benefit immensely from restoration of *Diadema* to reef areas. Restoration may occur naturally, and there are indications that some recovery is occurring in isolated areas of the Caribbean, Jamaica, Belize, and other areas, and even some small areas in the Dry Tortugas have populations of large urchins about two years old that were in densities of 0.4-0.8 urchins/m^2 (Chiappone et al. 2001). These remote populations are probably the source of the recruits that appear on the rubble zones of Keys reefs in the late summer and fall months.

Restoration of *Diadema*, however, has not occurred in the 20 years since the Caribbean-wide mass mortality of 1983-84, and very low larval densities and extensive predation on juvenile and adult urchins may prevent (Lessios 1995) or greatly delay natural restoration of pre-die-off densities of this species. Our study demonstrates that a program of continuous movement of juveniles from settlement on reef crest rubble zones to specific deeper reef areas can establish and maintain relatively dense populations of *Diadema* in small reef areas. The continuous placement of juvenile urchins on these areas after initial translocation of a population of about $2/m^2$ at a rate of about $1/m^2$ per year would substitute for natural recruitment and maintain a reproductively effective population. This would serve two purposes. First, it would restore small reef areas, perhaps in marine protected areas, to a coral-dominated ecology that will allow settlement and growth of corals under historical environmental conditions, which would be an important research tool and a reservoir of natural coral growth. And second, it would establish small populations of reproductively active *Diadema* that will increase the density of larval *Diadema* in the waters downstream of these populations. The immense fecundity of adult female *Diadema* greatly enhances the importance of even small populations of reproductively active adults. Such translocation and monitoring programs would not be expensive and could be done with volunteer personnel, and could be instrumental in aiding the recovery of this keystone herbivore to the reefs of the Florida Keys.

Acknowledgments

We would like to thank the Florida Keys National Marine Sanctuary for funding this project and the FKNMS staff, especially Billy Causey, Brian Keller, and Joanne Delaney for support and aid in establishing the project. The design and implementation of the project was greatly aided by the efforts of Joanne Delaney and Brian Keller of the FKNMS staff and also by Mark Chiappone, Dione Swanson, and Steven Miller of the Center for Marine Science Research and NOAA's National Undersea Research Center. Our wives, Denise Nedimyer and Barbara Moe also graciously supported the extensive time and effort that went into the successful completion of this project. Dr. Michael O. Stone and Kelly Nedimyer aided in the initial fieldwork. This project was conducted under FKNMS permit 2001-069.

References

Carpenter, R.C. 1984. Predator and population density control of homing behavior in the Caribbean echinoid, *Diadema antillarum*, Philippi. Mar. Biol. 82: 101-108.

Chiappone, M., S.L. Miller, D.W. Swanson, J.S. Ault, and S.G. Smith. 2001. Comparatively high densities of the long-spined sea urchin in the Dry Tortugas, Florida. Coral Reefs 20: 137-138.

Chiappone, M, D.W. Swanson, and S.L. Miller. 2002. Density, spatial distribution and size structure of sea urchins in Florida Keys coral reef and hard bottom habitats. Mar Ecol Prog Ser. 235: 117-126.

Bak, R.P.M. 1985. Recruitment patterns and mass mortalities in the sea urchin, *Diadema antillarum*. Proc. 5th Int. Coral Reef Cong. 5: 267-272.

Forcucci, D. 1994. Population density, recruitment and 1991 mortality event of *Diadema antillarum* in the Florida Keys. Bull. Mar. Sci. 54(3): 917-928.

Lessios, H.A. 1995. *Diadema antillarum* 10 years after mass mortality: still rare despite help from a competitor. Proc. R. Soc. Lond. B 259: 331-337.

Levitan, D.R. 1988. Asynchronous spawning and aggregative behavior in the sea urchin *Diadeama antillarum*. Pages 181-186 *in* R.D. Burke, P.V. Mladenov, P. Lambert, and R.L. Parsley, eds. Echinoderm biology, A.A. Balkema, Rotterdam.

Levitan, D.R. 1991. Influence of body size and population density on fertilization success and reproductive output in a free-spawning invertebrate. Biol. Bull. 181: 261-268.

Ogden, J.C., and R.C. Carpenter. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Florida). Long-spined black sea urchin. U.S. Fish and Wildlife Service. Biol. Rep. 82 (11.77). U.S. Army Corps of Engineers, TR EL-82-4. 17 pp.

One-year Response of Florida Keys Patch Reef Communities to Translocation of Long-spined Sea Urchins (*Diadema antillarum*)

Mark Chiappone, Dione Swanson, and Steven Miller (Center for Marine Science Research and NOAA's National Undersea Research Center, University of North Carolina at Wilmington, Key Largo, FL)

Abstract

A one-year experiment was conducted to determine the efficacy of urchin translocations and resulting benthic community effects on Florida Keys patch reefs. Small (1-1.5 cm test diameter) long-spined sea urchins (*Diadema antillarum*) were collected from back reef rubble zones and transported to two experimental patch reefs during September-December 2001. Changes to community structure were assessed on two experimental and two control patch reefs prior to and one year after the urchin translocation, including percent cover, sponge and cnidarian species richness, and juvenile coral density. Urchin densities on the experimental patch reefs one year after the translocation averaged nearly 1 individual/m^2, similar to urchin density estimates in the Florida Keys prior to the 1983-84 mass mortality event. The coverage of stony corals and crustose coralline algae increased, while the coverage of brown foliose algae declined on experimental patch reefs. In contrast, stony coral and crustose coralline algal cover declined on control patch reefs, but increased for brown foliose algae. Juvenile coral densities increased at all sites, but density increases were markedly greater on both experimental sites, reflecting greater densities of smaller juveniles (< 1.5 cm diameter), especially *Porites astreoides* and *Siderastrea siderea*. Greater juvenile densities on experimental reefs may have resulted from more available space for settlement, lower post-settlement mortality from algal overgrowth, or enhanced settlement sites due to increased coverage of crustose coralline algae compared to control reefs. These results are similar to previous investigations of the effects of artificially enhanced or naturally recovering urchin densities on coral reef benthos, especially as they pertain to changes in algal composition and juvenile coral densities. However, other factors, such as storms that frequented the area during the study, are also possible contributors to the temporal patterns documented. Future surveys will monitor the survivorship of the resident adult urchins on experimental reefs and additional changes to benthic community structure that may occur.

Introduction

Understanding the factors responsible for ecosystem change in coral reef ecosystems remains a challenge (Hughes and Connell 1999). This is especially true in the Florida Keys (Dustan and Halas 1987; Porter and Meier 1992; Chiappone and Sullivan 1997), where reefs are subtropical and subjected to substantial continental influence and densely populated shorelines (Marszalek et al. 1977; Jaap 1984). Evidence of coral reef decline is associated with diseases (Dustan 1977; Richardson et al. 1998; Santavy et al. 2001); physical impacts from storm events, but also human-related impacts such as vessel groundings and anchoring (Dustan and Halas 1987); thermal stress, especially large-scale coral mortality after winter cold fronts (Roberts et al. 1982); and coral bleaching during hyperthermic events (Jaap et al. 1988). Decreased herbivory, principally due to the 1983-84 mortality of the long-spined sea urchin *Diadema antillarum* (Lessios et al. 1984), is widely thought to be a major factor explaining increased macroalgal growth on reefs throughout the Caribbean (Hughes et al. 1985; Carpenter 1990), including the Florida Keys (Lapointe 1989; Hallock et al. 1993; Chiappone et al. 1997), but questions about the relative importance of top-down (e.g., predator control) versus bottom-up control (e.g., nutrient availability) remain (Lapointe 1997; Hughes et al. 1999).

Prior to the mass mortality of *Diadema antillarum* in 1983-84, sea urchins attained high (> 20 individuals/m^2) densities in many locations throughout the Caribbean (Sammarco et al. 1974; Hay 1984; Hunte et al. 1986). For example, *D. antillarum* densities on the north coast of Jamaica ranged from 5 to 70 individuals/m^2 in particular habitats (Sammarco 1980; Hughes et al. 1985). In the Florida Keys, however, the few historical data available indicate that sea urchin densities were lower (up to 4-5 individuals/m^2) (Kier and Grant 1965; Bauer 1976, 1980). The effects of the sea urchin mass mortality were evident and widespread, manifested in dramatic increases in algal cover and species composition and decreased coral cover and recruitment (Liddell and Ohlhorst 1986; Hughes et al. 1987). Other sea urchin species did not compensate for the loss of *D. antillarum* (Hughes et al. 1987), but recent observations in Jamaica indicate that other sea urchin species may move to habitats formerly dominated by *D. antillarum*, such as *Tripneustes ventricosus* (Woodley 1999b; Moses and Bonem 2001). Despite lower historical sea urchin densities in the Florida Keys, a general trend of increased algal cover was noted qualitatively after the mass mortality in 1983 at several upper Florida Keys bank reefs (Jaap et al. 1988) and in photo-monitoring stations at six locations from Biscayne National Park to Looe Key (Porter and Meier 1992). Seven years after the mass mortality affected *D. antillarum* in the Florida Keys, a second disease event, after modest recovery to 0.30 to 0.58 individuals/m^2, once again attacked the Florida Keys population, resulting in declines to < 0.01 individuals/m^2 (Forcucci 1994). Since the second Florida Keys mortality event, large-scale surveys during 1999-2001 confirm the poor recovery of sea urchins in multiple habitat types (Chiappone et al. 2002a, b), with notable exceptions in selected shallow-water patch reefs and hard-bottom areas in the Dry Tortugas (Chiappone et al. 2001). Anecdotal surveys indicate that there is continued (over the last 10 years) pulse recruitment events of sea urchins during June through September, and numerous smaller individuals (< 1.5 cm test diameter [TD]) can be observed in rubble zones on the shoreward side of bank reefs such as Pickles Reef and Conch Reef (K. Nedimyer, personal observation). The recruitment and survival of juvenile sea urchins in these areas may be a function of adequate habitat (e.g., loose rocks and crevices) that effectively minimizes post-settlement mortality from predators that probably affects survivorship in other habitat types. However, the juvenile sea urchins that settle in these rubble zones do not survive though the winter, probably due to scouring and over-toppling during storm events. At this time, juvenile sea urchins do not appear to recruit in substantial numbers to other reef habitats in the Florida Keys.

A multi-faceted project was undertaken during September 2001 to explore the efficacy of translocating juvenile *Diadema antillarum* that recruited to rubble zones to nearby patch reefs, to track the survivorship of translocated sea urchins, and to ascertain the effects of increased sea urchin densities on patch reef community structure (see previous chapter). There is interest in this previously ubiquitous element of the Florida Keys reef ecosystem, because there is expectation that sea urchin recovery will help to reverse the trend in macroalgal expansion at the expense of reef-building corals observed on particular reefs (Porter and Meier 1992; Edmunds and Carpenter 2001). This study describes a one-year assessment of the effects of urchin translocation on patch reef community structure, focusing on changes in benthic cover, species richness, juvenile coral density, and urchin density and test diameter. The null hypothesis tested in this study is that there will be no difference in community structure between reefs with and without translocated *D. antillarum*.

Materials and methods

Study Sites

Four patch reefs roughly similar in size, shape, depth, and location were selected for study inshore of Pickles Reef in the upper Florida Keys, offshore of Plantation Key (Tavernier). Patch reefs were chosen as the areas for sea urchin translocation because of their relatively small size and abundance of microhabitats (e.g., large coral heads, crevices) to place translocated sea urchins from nearby back reef rubble habitats. The study sites are characterized as dome-shaped patch reefs at 7.5-9 m (25-30 feet) depth in Hawk Channel, a V-shaped basin separating the Pleistocene islands of the Florida Keys from the offshore bank-barrier reef tract. Initial benthic sampling was conducted during August 31 to September 1, 2001, followed by three months of urchin translocation expeditions from September through December. Re-surveys of patch reef community structure were conducted during September 18, 2002, approximately one year after the initial urchin translocation.

Experimental patch reef #1 (ER #1; 24^{o} 59.177'N, 80^{o} 26.099'W) is roughly circular in shape and 10-11 m in diameter. Several large coral heads (0.5-1 m diameter), mostly represented by *Montastraea cavernosa*, flank the southern end of the reef (Fig. 1). The site is bounded by dense seagrass and is immediately adjacent to ER #2 to the west. The second experimental patch reef had fewer large coral heads, but there were some large *Siderastrea siderea* colonies on the southern side of the reef (Fig. 1). ER #2 is approximately 11 m x 9 m along the N-S and E-W axes, respectively. One of the two control sites, control patch reef #3 (CR #3; 24^{o} 59.182'N, 80^{o} 26.119'W), is separated from ER #2 by a moderately dense seagrass bed. This site is 7.5-8.0 m deep with some moderate-sized *Montastraea faveolata* colonies, but has less vertical relief than the experimental sites (Fig. 2). The second control patch reef (CR #4; 24^{o} 59.101'N, 80^{o} 26.128'W) is west of the first three patch reefs and has a less consolidated reef framework, with the interior of the patch reef largely comprised of rubble, sand overlying hard-bottom, and deeper pockets of sediment (Fig. 2). Large colonies of *Diploria labyrinthiformis* and *M. cavernosa* occur on the southern side of the reef.

Urchin Translocation

During September to December 2001, several translocations of juvenile *Diadema antillarum* were made from the rubble zone near Pickles Reef to the two experimental patch reefs (see previous chapter). Maps were constructed of the two experimental sites to facilitate re-surveys of sea urchins to assess survivorship after translocation. A total of 455 juvenile sea urchins were moved to ER #1 and 238 individuals moved to ER #2. The numbers of sea urchins translocated to the experimental reefs were based upon the area of the reef, availability of sea urchins at the time of translocation, and the number of crevices available to place individuals. During September to December 2001, each site was visited six to eight times to release new sea urchins and/or to survey survivorship. From May to October 2002, each experimental site was re-visited an additional three times to assess the number of surviving sea urchins.

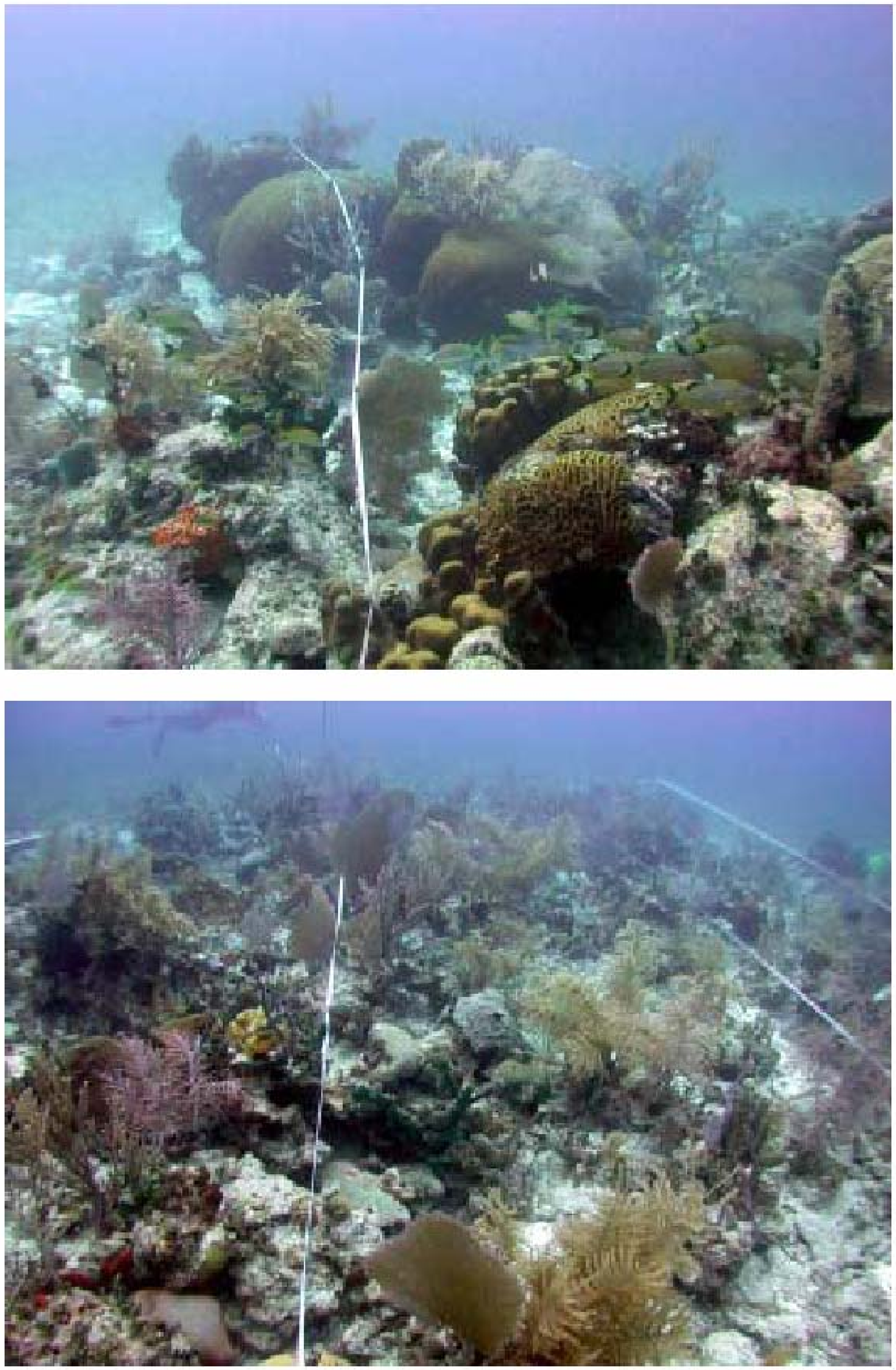


Figure 1. Underwater photographs of sea urchin experimental sites #1 (top) and #2 (bottom), taken during September 2002.

Figure 2. Underwater photographs of sea urchin control sites #3 (top) and #4 (bottom), taken during September 2002.

Benthic Surveys
A suite of variables was measured to evaluate the possible responses of the experimental patch reefs to the translocation of sea urchins, following procedures summarized in Miller et al. (2002). Before and one year following the urchin translocation, percent cover, species richness, topography, juvenile coral density, urchin density and size, gorgonian density and size, and coral density, size, and condition were assessed. At each patch reef, four 10-m transects were haphazardly placed along the long axis of each site (Fig. 1). Transects served as the basis for measuring coverage, species richness, and the densities and sizes of macro-invertebrates. Percent coverage was assessed using the linear point-intercept method, in which 100 points per transect, spaced at 10-cm intervals, were sampled to determine the type of benthos underlying each point. The presence and total numbers of sponges, stony corals, and gorgonians were surveyed 0.4 m out on each side of the four transects, yielding a transect area of 8 m^2 and a total sampling area of 32 m^2 for each patch reef. Sea urchins were surveyed in a similar fashion to determine the density of particular species and the test diameter (cm) of individuals found. Gorgonian and coral density were surveyed on two of the four transects per site in 0.4 m swaths on one transect side (4 m^2 transect area). Gorgonians were surveyed for the species, colony number, and maximum height using four size classes (< 20 cm, 20-50 cm, 50-100 cm, and > 100 cm). Juvenile corals (< 4 cm maximum diameter) were assessed on two transects per site by randomly placing ten 0.65 m x 0.48 m quadrats (total area of 3.12 m^2 per transect) along two of the four transects. Topographic complexity was assessed along all four transects by measuring the maximum and minimum depth of each transect using a digital depth gauge and recording the maximum vertical relief in 0.4 m x 10 m areas. Within each 0.4 m x 10 m transect, an estimate of the percentage of the transect area with a given topographic profile was assessed using five relief categories: < 0.2 m, 0.2-0.5 m, 0.5-1.0 m, 1.0-1.5 m, and > 1.5 m. All surveys, with the exception of video, were completed using pencils and plastic slates, and typically one site could be completed in 90 minutes of underwater bottom time with three trained personnel.

Results
Patch Reef Characteristics
The four patch reefs selected for study were at a similar depth and had similar maximum relief (Table 1). However, both experimental sites tended to have a greater percentage of the patch reef areas with 0.2-0.5 m of vertical relief (Fig. 1) compared to control sites (Fig. 2). The experimental sites had areas of higher relief represented by 1+ m diameter coral heads that were the principal areas used to translocate juvenile urchins from rubble zones. No other significant differences in topography were noted between experimental and control sites from year to year during the course of the study.

Benthic coverage at both experimental sites was dominated by algal turf, brown foliose algae (*Dictyota*), and scleractinian corals, especially *Montastraea cavernosa* and *Siderastrea siderea*. At ER #1, corals (20 species) and sponges (35 species) were represented by many more species compared to gorgonians (8 species). Gorgonian density was relatively low (3.88 colonies/m^2) and mostly dominated by small (< 20 cm) and medium-size (20-50 cm) sea fans (*Gorgonia ventalina*) and sea plumes (*Pseudopterogorgia* spp.). At ER #2, a larger percentage of the patch reef was comprised of sand and sand overlying hard-bottom compared to ER #1. Corals and gorgonians were represented by 15 and 18 species, respectively, while sponges were the most speciose (35 taxa). Gorgonian density on ER #2 was twice as high (8.50 colonies/m^2) compared to the first experimental patch, but was similarly dominated by sea plumes and sea fans. The primary difference in gorgonian densities between the two experimental sites was attributed to more *Eunicea* species at ER #2. Like ER #1, gorgonians were represented by mostly small (< 20 cm height) to intermediate-sized (20-50 cm) colonies at ER #2.

Table 1. Physical characteristics of experimental (top) and control (bottom) patch reefs, expressed in terms of the mean (1 SE) minimum and maximum depth of surveyed transects, mean (1 SE) maximum vertical relief, and estimated mean (1 SE) percentage of site with given topographic relief. Data are based upon surveys of four 10 m x 0.4 m transects per site each year.

Experimental patch reefs

Physical variable	Experimental site #1		Experimental site #2		Combined experimental	
	2001	2002	2001	2002	2001	2002
Minimum depth (m)	7.5 (0.0)	7.7 (0.1)	7.4 (0.1)	7.6 (0.1)	7.5 (0.1)	7.7 (0.1)
Maximum depth (m)	7.6 (0.1)	8.0 (0.1)	7.5 (0.0)	8.0 (0.1)	7.6 (0.1)	8.0 (0.0)
Maximum relief (cm)	82 (16)	79 (13)	41 (7)	45 (4)	62 (21)	62 (17)
Relief area (%)						
< 0.2 m	72.5 (4.3)	61.3 (8.3)	63.8 (7.2)	70.0 (7.4)	68.2 (4.4)	65.7 (4.4)
0.2-0.5 m	25.0 (4.6)	23.8 (5.5)	35.0 (7.1)	28.8 (7.5)	30.0 (5.0)	26.3 (2.5)
0.5-1.0 m	1.3 (1.3)	15.0 (6.1)	1.3 (1.3)	1.3 (1.3)	1.3 (0.0)	8.2 (6.9)
1.0-1.5 m	1.3 (1.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)
> 1.5 m	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Control patch reefs

Physical variable	Control site #3		Control site #4		Combined control	
	2001	2002	2001	2002	2001	2002
Minimum depth (m)	7.4 (0.1)	7.5 (0.0)	8.0 (0.1)	7.7 (0.1)	7.7 (0.2)	7.6 (0.1)
Maximum depth (m)	7.5 (0.0)	7.5 (0.0)	8.1 (0.0)	7.8 (0.0)	7.8 (0.2)	7.7 (0.1)
Maximum relief (cm)	42 (6)	44 (7)	63 (17)	61 (19)	53 (11)	53 (9)
Relief area (%)						
< 0.2 m	77.5 (3.2)	78.8 (4.7)	76.3 (7.2)	83.8 (5.5)	76.9 (0.6)	81.3 (2.5)
0.2-0.5 m	21.3 (2.4)	18.8 (2.4)	17.5 (6.0)	10.0 (2.0)	19.4 (1.9)	14.4 (4.4)
0.5-1.0 m	1.3 (1.3)	2.5 (2.5)	5.0 (2.0)	6.3 (3.8)	3.2 (1.9)	4.4 (1.9)
1.0-1.5 m	0.0 (0.0)	0.0 (0.0)	1.3 (1.3)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)
> 1.5 m	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Both control sites were similarly dominated by algal turf, brown foliose algae, especially *Dictyota*, crustose coralline algae, stony corals, and sponges. CR #3 had large areas of sand and sand overlying hard-bottom and was patchier than the experimental sites. The species richness of corals, gorgonians, and sponges was relatively similar to the experimental sites. Gorgonian density at CR #3 was similar to ER #2 (about 7.1 colonies/m^2), mostly represented by small (< 20 cm) to intermediate-sized (20-50 cm) colonies. CR #4 had greater topographic relief than the first control site. Vertical relief at this site was up to nearly 1 m due to the presence of large coral heads on the southern end of the reef. Brown foliose algae and green calcareous algae (*Halimeda*) comprised less coverage that at the other sites. While coral cover was relatively high, there was considerable variability due to the localized occurrence of large coral heads on one end of the patch reef and large areas of sand and rubble in the interior of the site. Species richness of corals, gorgonians, and sponges was similar or slightly lower at CR #4 compared to the other three patch reefs. Gorgonian density was low (4.3 colonies/m^2) and similar to ER #1, and was almost exclusively comprised of sea plumes and sea fans, most of which were < 20 cm in height.

Tables 2 through 5 list the stony coral, gorgonian, and sponge species recorded within transects during the two sampling periods. Stony coral species richness was slightly lower on control patch reefs, usually by two to three species (Table 2). *Diploria strigosa*, *Leptoseris cucullata*, *Madracis decactis*, and *Montastraea annularis* were observed on one or both experimental sites, but not on control sites, while *Meandrina meandrites* was observed on control sites, but not on experimental sites. Gorgonian species richness was slightly greater at the experimental sites (Table 3). *Erythropodium caribaeorum*, *Plexaura homomalla*, and *Eunicea succinea* were recorded on experimental sites, but not control sites. Sponge species richness was relatively similar among both experimental and control sites (Tables 4-5), but there was a larger discrepancy between control sites during 2001 to 2002. However, many of the species not recorded at the control sites during 2002 were predominately cryptic sponges. Few changes were noted in species richness from year to year for these species groups.

Sea Urchin Translocation Effects

Not surprisingly, experimental sites showed an increase in the density (Table 6) and mean test diameter (Table 7) of *Diadema antillarum* between 2001 and 2002, principally due to the effects of translocation (Fig. 3). Urchin densities at the control sites either exhibited no change or a slight density decrease. The densities of other sea urchin species at both experimental and control sites did not change markedly during the year of study. Although the change in mean size and size distribution of *D. antillarum* at the experimental sites largely reflected the growth of translocated urchins during the year (Fig. 4), sea urchin recruits in the 1.0-1.5 cm TD size class were also evident at both experimental sites.

Changes in the coverage of different benthic components exhibited some marked differences between experimental (Table 8) and control sites (Table 9). Percent coral cover increased on both experimental patch reefs, while both control patch reefs showed declines (Fig. 5). The magnitude of change in percent coral cover on the experimental sites (9.8% to 15.3%) was +5.5% absolute and +56% relative. Coral cover on the control patch reefs declined from 9.1% to 6.8%, representing a –2.4% absolute change and –26% relative change during the study. The temporal patterns in coral cover may be partially due to the random location of transects from year to year and is not considered significant, especially since we did not see evidence of substantial coral growth or mortality. Sponge cover decreased on experimental patch reefs from a mean of 7.4% to 5.3%, but exhibited a slight increase on control patch reefs from 5.3% to 6.0%.

Different algal functional groups by far exhibited the most notable changes in benthic community structure between experimental and control patch reefs. Algal turf exhibited a slight decrease on both experimental sites from 28.6% to 24%, representing a -4.6% absolute change and -16.2% relative change. In contrast, control sites exhibited a slight increase from 23.4% to 27.8%, representing a +4.4% absolute change and +18.7% relative change. The coverage of crustose coralline algae (CCA) exhibited the most significant difference between experimental and control patch reefs during the study (Fig. 5). Large increases (7.5% to 19%) were documented on both experimental sites, representing a +11.5% absolute change and +153% relative change. In contrast, control sites exhibited no discernible temporal pattern in CCA cover,

Table 2. Species richness (numbers of species) of stony corals (Milleporina and Scleractinia) observed within four 15 m x 0.8 m (12 m^2) transects on experimental (top) and control (bottom) patch reefs before and one year after urchin translocation.

Experimental patch reefs

Coral species	Experimental site #1		Experimental site #2		Combined experimental	
	2001	2002	2001	2002	2001	2002
A. agaricites	1	1	1	1	1	1
A. fragilis			1	1	1	1
A. humilis	1	1	1	1	1	1
C. natans	1	1			1	1
D. stokesi	1	1	1	1	1	1
D. clivosa			1			
D. labyrinthiformis	1	1		1	1	1
D. strigosa	1	1		1	1	1
E. fastigiata	1				1	
L. cucullata			1	1	1	1
M. decactis	1				1	
M. alcicornis	1	1	1	1	1	1
M. annularis	1	1		1	1	1
M. faveolata	1	1	1	1	1	1
M. cavernosa	1	1	1	1	1	1
P. astreoides	1	1	1	1	1	1
P. branneri		1		1		1
P. porites divaricata	1	1	1		1	1
P. porites furcata	1	1	1	1	1	1
P. porites porites	1			1	1	1
S. radians	1	1	1	1	1	1
S. siderea	1	1	1	1	1	1
S. bournoni	1	1	1		1	1
S. michelini	1	1		1	1	1
Total species	20	18	15	18	22	21

Control patch reefs

Coral species	Control site #3		Control site #4		Combined control	
	2001	2002	2001	2002	2001	2002
A. agaricites	1	1	1	1	1	1
A. fragilis	1				1	
A. humilis	1			1	1	1
C. natans			1		1	
D. stokesi	1	1	1	1	1	1
D. clivosa				1		1
D. labyrinthiformis	1		1	1	1	1
E. fastigiata		1		1		1
F. fragum			1		1	
L. cucullata		1				1
M. meandrites	1				1	
M. alcicornis	1	1	1	1	1	1
M. faveolata	1	1	1	1	1	1
M. cavernosa	1	1	1	1	1	1
P. astreoides	1	1	1	1	1	1
P. branneri	1	1	1		1	1
P. porites divaricata	1	1	1		1	1
P. porites furcata	1	1	1	1	1	1
P. porites porites		1				1
S. radians	1	1	1	1	1	1
S. siderea	1	1	1	1	1	1
S. bournoni	1	1	1	1	1	1
S. michelini	1	1		1	1	1
Total species	17	16	15	15	19	19

Table 3. Species richness (numbers of species) of gorgonians (Octocorallia) observed within four 15 m x 0.8 m (12 m^2) transects on experimental (top) and control (bottom) patch reefs before and one year after urchin translocation.

Experimental patch reefs

Gorgonian species	Experimental site #1		Experimental site #2		Combined experimental	
	2001	2002	2001	2002	2001	2002
E. caribaeorum			1	1	1	1
E. calyculata		1	1		1	1
E. fusca			1	1	1	1
E. laciniata		1	1	1	1	1
E. mammosa	1	1	1	1	1	1
E. succinea	1		1		1	
E. tourneforti		1	1	1	1	1
G. ventalina	1	1	1	1	1	1
M. elongata		1		1		1
M. muricata			1	1	1	1
M. flavida	1	1	1	1	1	1
P. flexuosa		1	1	1	1	1
P. homomalla	1		1	1	1	1
P. dichotoma			1	1	1	1
Pseudoplexaura sp.	1	1	1	1	1	1
P. flagellosa		1	1	1	1	1
P. acerosa	1	1	1	1	1	1
P. americana	1	1	1	1	1	1
P. rigida		1				1
P. citrina			1		1	
Total species	8	13	18	16	18	18

Control patch reefs

Gorgonian species	Control site #3		Control site #4		Combined control	
	2001	2002	2001	2002	2001	2002
B. asbestinum	1				1	
E. calyculata	1	1	1		1	1
E. fusca	1	1			1	1
E. laciniata	1		1		1	
E. mammosa	1	1	1	1	1	1
E. tourneforti	1	1			1	1
G. ventalina	1	1	1	1	1	1
M. elongata		1				1
M. muricata	1	1			1	1
M. flavida	1	1	1		1	1
P. flexuosa	1	1	1	1	1	1
P. dichotoma	1	1	1	1	1	1
Pseudoplexaura sp.	1	1	1	1	1	1
P. flagellosa	1	1			1	1
P. acerosa	1	1	1	1	1	1
P. americana	1	1	1	1	1	1
P. rigida		1				1
P. citrina		1				1
Total species	15	16	10	7	15	16

where coverage actually decreased at CR #3 and only slightly increased at CR #4 (Table 9). The overall change in CCA cover on control sites was from 7.8% in 2001 to 8.3% in 2002, representing a +0.5% absolute change and +6.5% relative change.

Table 4. Species richness (numbers of species) of sponges observed within four 15 m x 0.8 m (12 m^2) transects on experimental patch reefs before and one year after urchin translocation.

Sponge species	Experimental site #1		Experimental site #2		Combined experimental	
	2001	2002	2001	2002	2001	2002
A. clathrodes		1				1
A. wiedenmayaari	1	1	1	1	1	1
A. compressa	1	1	1	1	1	1
A. viridis	1	1	1	1	1	1
A. varians		1		1		1
A. cauliformis	1	1	1	1	1	1
A. fistularis			1	1	1	1
A. lacunosa	1	1			1	1
C. vaginalis	1	1	1	1	1	1
C. nucula	1	1	1	1	1	1
C. deletrix	1	1	1	1	1	1
Cliona sp.	1	1	1		1	1
D. etheria	1	1	1	1	1	1
D. janiae	1	1	1	1	1	1
Halisarca sp.	1	1	1	1	1	1
I. birotulata	1	1	1	1	1	1
I. campana	1	1	1	1	1	1
I. felix	1	1	1	1	1	1
I. strobilina	1	1	1	1	1	1
M. barbadensis	1	1	1	1	1	1
M. unguifera	1	1	1	1	1	1
M. laevis	1	1			1	1
N. digitalis	1	1	1	1	1	1
N. erecta	1	1	1	1	1	1
P. acanthifolium	1	1	1	1	1	1
P. lunaecharta	1	1	1	1	1	1
P. crassa	1	1	1	1	1	1
Ptilocaulis sp.		1	1	1	1	1
R. venosa		1	1	1	1	1
S. coralliphagum	1	1	1	1	1	1
S. vesparium	1		1		1	
S. tenerrima	1	1	1	1	1	1
T. ignis	1	1	1	1	1	1
U. ruetzleri	1				1	
V. rigida	1	1	1	1	1	1
X. muta				1		1
Unknown blue tube	1		1		1	
Unknown carmine	1		1		1	
Unknown mauve		1				1
Unknown orange		1	1		1	1
Unknown encrusting	1		1		1	
Unknown red sponge	1	1	1	1	1	1
Total species	35	35	35	31	38	37

Green foliose algae, primarily represented by *Ventricaria ventricosa* and *Caulerpa verticillata*, showed little change on experimental sites (from 0.9% in 2001 to 0.4% in 2002) (Table 8), but mixed patterns were evident on control sites (Table 9). The coverage of green calcareous algae, primarily represented by *Halimeda* spp., showed little change on experimental sites (3.8% to 3.1%) compared to control sites, where mean coverage increased from 1.8% to 3.8%, representing a +2% absolute change and +114% relative change. The coverage of brown foliose algae (BFA), primarily represented by *Dictyota* spp., greatly declined on experimental patch reefs (Fig. 5), especially at ER #1, where coverage decreased from 11% to 1.8%. Overall, the coverage of BFA on experimental sites decreased from 10% to 5.1%, representing a –4.9% absolute decline and –48.7% relative decline. In contrast, control sites either exhibited no change or an increase in coverage of BFA (Table 9).

Table 5. Species richness (numbers of species) of sponges observed within four 15 m x 0.8 m (12 m^2) transects on control patch reefs before and one year after urchin translocation.

Sponge species	**Control site #3**		**Control site #4**		**Combined control**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
A. clathrodes	1				1	
A. wiedenmayaari	1	1	1	1	1	1
A. compressa	1	1	1	1	1	1
A. viridis	1	1			1	1
A. varians		1	1	1	1	1
A. archeri	1				1	
A. cauliformis	1	1	1	1	1	1
A. fistularis	1	1			1	1
A. lcaunosa		1				1
C. plicifera				1		
C. vaginalis	1	1	1		1	1
C. nucula	1	1	1	1	1	1
C. deletrix	1	1	1	1	1	1
Cliona sp.	1	1	1	1	1	1
C. vasculum	1				1	
D. etheria	1	1	1	1	1	1
D. janiae	1	1	1	1	1	1
Halisarca sp.	1		1		1	
I. birotulata	1	1	1	1	1	1
I. campana	1	1	1	1	1	1
I. felix	1	1	1	1	1	1
I. strobilina	1	1	1	1	1	1
M. barbadensis	1		1	1	1	1
M. unguifera		1	1	1	1	1
M. laevis	1	1			1	1
N. digitalis	1	1	1	1	1	1
N. erecta	1	1	1	1	1	1
P. acanthifolium	1	1	1	1	1	1
P. lunaecharta	1	1	1	1	1	1
P. crassa	1	1	1	1	1	1
Ptilocaulis sp.		1				1
R. venosa		1		1		1
S. coralliphagum	1	1	1	1	1	1
S. vesparium	1		1		1	
S. tenerrima	1	1			1	1
T. ignis	1	1	1		1	1
V. rigida	1	1			1	1
X. muta	1				1	
Unknown blue tube				1		
Unknown carmine			1		1	
Unknown orange	1	1			1	1
Unknown encrusting	1		1		1	
Unknown red sponge	1	1	1	1	1	1
Total species	35	32	28	25	38	33

Table 6. Mean (1 SE) density (no. individuals per m^2) of urchins observed within four 15 m x 0.8 m (12 m^2) transects on experimental and control patch reefs before and one year after urchin translocation.

Treatment	*Diadema antillarum*		*Echinometra viridis*		*Eucidaris tribuloides*	
	2001	2002	2001	2002	2001	2002
Experimental site #1	0	0.719 (0.219)	0.031 (0.031)	0	0.031 (0.031)	0.125 (0.051)
Experimental site #2	0	0.781 (0.299)	0.031 (0.031)	0	0.031 (0.031)	0.031 (0.031)
Pooled experimental	0	0.750 (0.172)	0.031 (0.020)	0	0.031 (0.020)	0.078 (0.033)
Control #3	0	0	0	0	0.031 (0.031)	0.063 (0.036)
Control #4	0.156 (0.079)	0.094 (0.060)	0	0	0.031 (0.031)	0.031 (0.031)
Pooled control	0.078 (0.047)	0.047 (0.033)	0	0	0.031 (0.020)	0.047 (0.023)

Table 7. Size frequency and mean (1 SE) test diameter (cm) of *Diadema antillarum* observed within four 15 m x 0.8 m (12 m^2) transects on experimental and control patch reefs before and one year after urchin translocation.

Treatment	No. surveyed		Size range (cm)		Mean diameter (cm)	
	2001	2002	2001	2002	2001	2002
Experimental site #1	0	23	0	1.3-5.3	0	4.2 (0.2)
Experimental site #2	0	25	0	1.1-5.2	0	4.1 (0.1)
Pooled experimental	0	48	0	1.1-5.3	0	4.2 (0.1)
Control #3	0	0	0	0	0	0
Control #4	5	3	1.8-6.7	3.4-5.3	3.6 (0.8)	4.5 (0.6)
Pooled control	5	3	1.8-6.7	3.4-5.3	3.6 (0.8)	4.5 (0.6)

Changes in the density and species composition of juvenile corals documented for the experimental and control sites are summarized in Table 10. A total of seven scleractinian coral species were observed as juveniles on the experimental sites in 2001 compared to nine species on the control sites. More species were found (11) on experimental sites in 2002, but one less species was recorded on control sites. Species recorded as juveniles on the experimental sites in 2002, but not in 2001, included *Agaricia fragilis*, *Eusmilia fastigiata*, and *Leptoseris cucullata*. Mean juvenile densities increased significantly on the experimental sites, from an average of 6.2 juveniles/m^2 to 15.3 juveniles/m^2, representing a +147% relative increase (Fig. 6). Mean densities also increased on the control sites, but not to the same degree, from 6.6 juveniles/m^2 to 9.9 juveniles/m^2 or a +51% relative increase. Notable increases in the densities of *Porites astreoides*, *P. porites*, and *Siderastrea siderea* were noted for both experimental and control sites from 2001 to 2002. The mean size (maximum diameter) of juvenile scleractinian corals for experimental and control sites is summarized in Table 11. For the most abundant species on experimental patch reefs, mean juvenile size decreased (e.g., *P. astreoides* and *S. siderea*) or showed no substantial change (e.g., *S. radians*). On control patch reefs, except for many smaller juveniles of *S. siderea* observed in 2002, most species exhibited no change or increases in mean juvenile size.

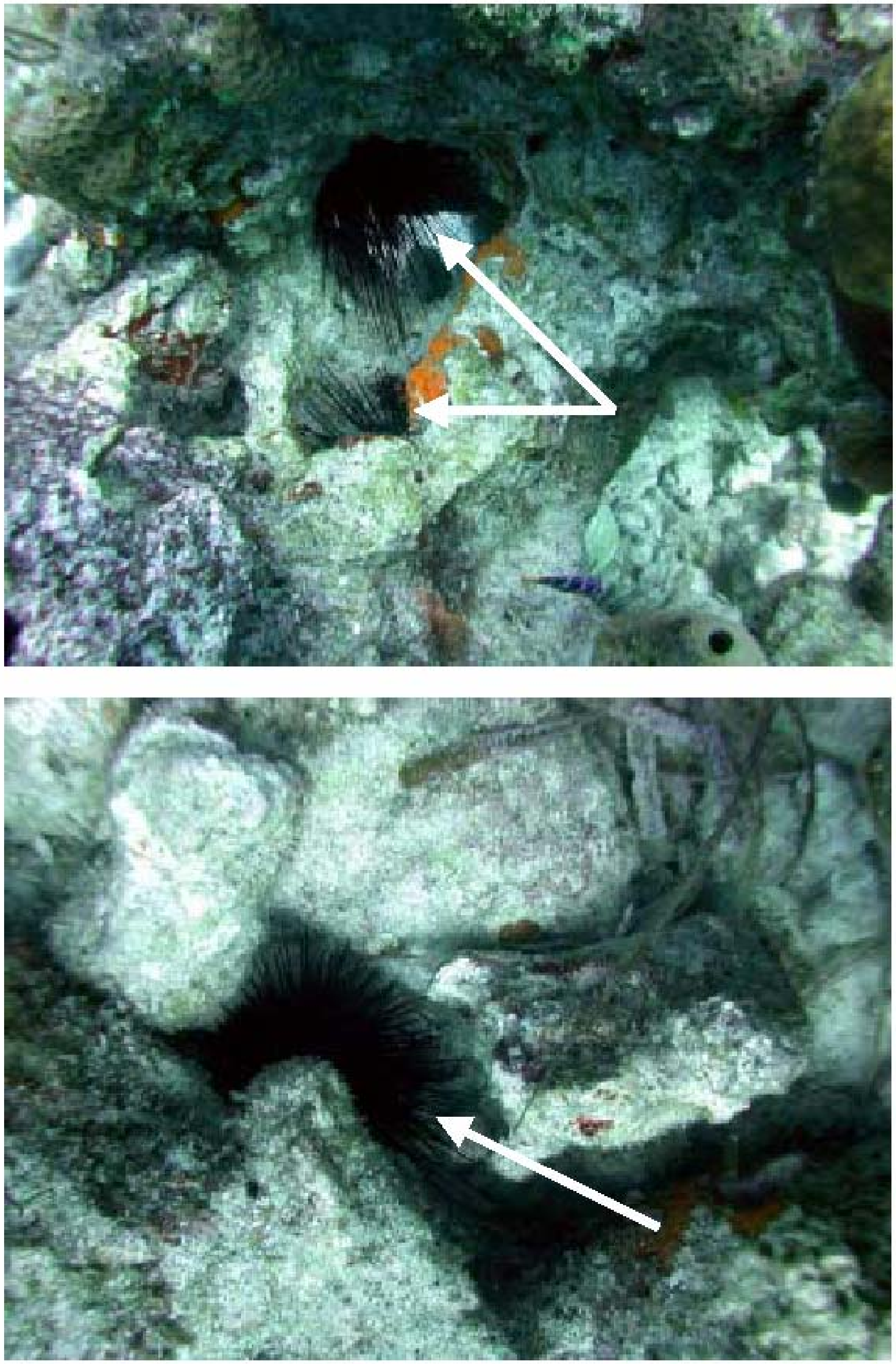


Figure 3. Individual *Diadema antillarum* at ER #1, one year after translocation.

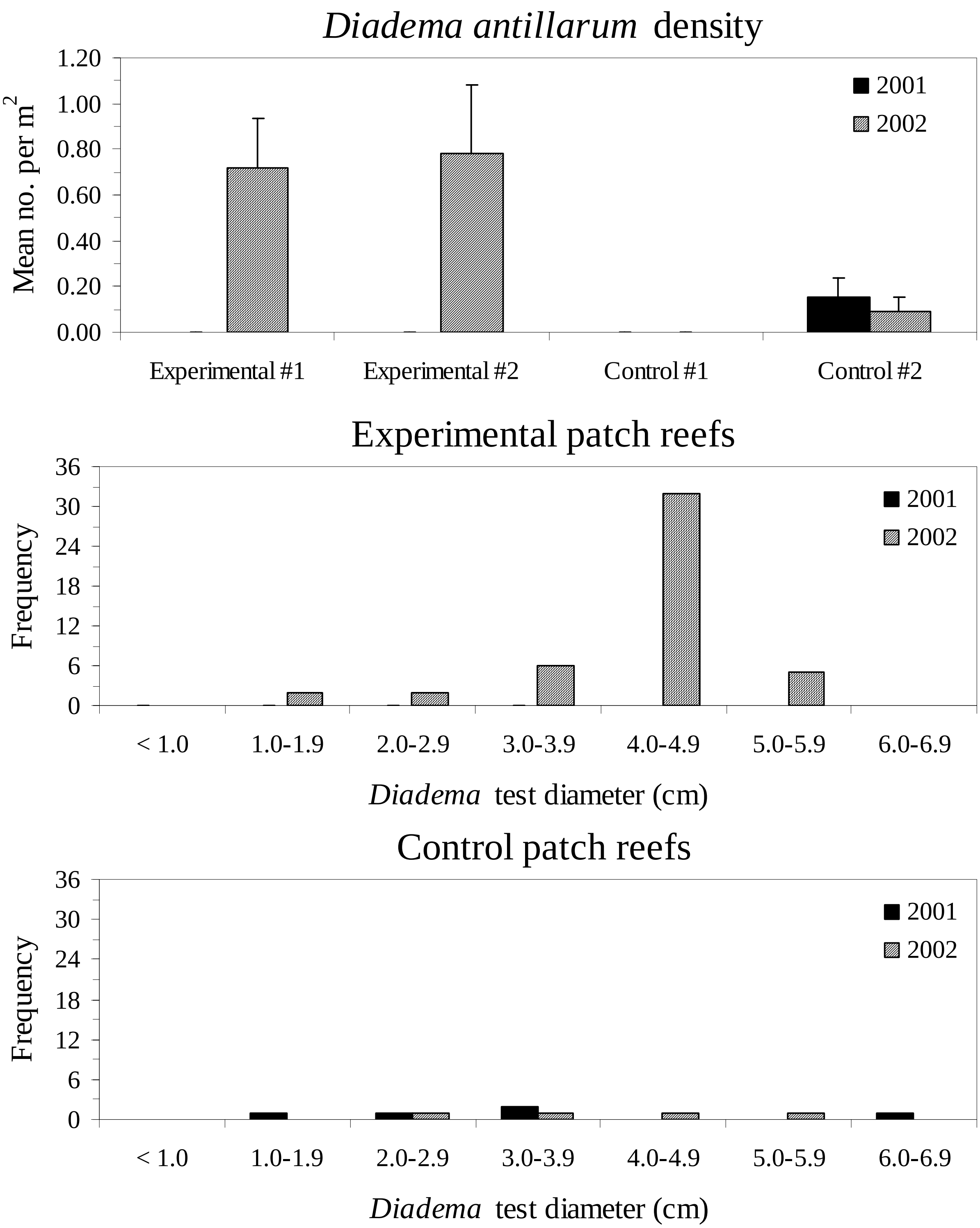


Figure 4. Changes in mean density (no. individuals per m^2) and test size distribution of *Diadema antillarum* before and one year after urchin translocation on Florida Keys patch reefs. Error bars represent one standard error. "Control #1 and #2" = CR #3 and CR #4.

Table 8. Mean (1 SE) percent cover of major benthic groups on experimental patch reefs before and one year after urchin translocation. Sample size = 4 transects per site per year and 100 points per transect.

Bottom type	**Experimental site #1**		**Experimental site #2**		**Combined experimental**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
A. agaricites	0.25 (0.25)		0.25 (0.25)		0.25 (0.00)	
C. natans	1.00 (1.00)				0.50 (0.50)	
D. stokesi			0.25 (0.25)	0.50 (0.29)	0.13 (0.13)	0.25 (0.25)
D. labyrinthiformis		0.25 (0.25)		0.50 (0.50)		0.38 (0.13)
D. strigosa		1.75 (1.03)				0.88 (0.88)
M. alcicornis		0.50 (0.29)	0.25 (0.25)		0.13 (0.13)	0.25 (0.25)
M. annularis	1.00 (1.00)	0.25 (0.25)			0.50 (0.50)	0.13 (0.13)
M. cavernosa	6.50 (4.57)	14.50 (3.59)	1.00 (0.71)	0.75 (0.75)	3.75 (2.75)	7.63 (6.88)
M. faveolata		1.00 (0.58)	0.25 (0.25)	1.00 (1.00)	0.13 (0.13)	1.00 (0.00)
P. astreoides	1.00 (0.41)	1.25 (0.63)	0.25 (0.25)	1.50 (0.96)	0.63 (0.38)	1.38 (0.13)
P. porites furcata	0.50 (0.29)			0.25 (0.25)	0.25 (0.25)	0.13 (0.13)
P. porites porites			0.25 (0.25)	0.25 (0.25)	0.13 (0.13)	0.13 (0.13)
S. radians	0.75 (0.25)	0.75 (0.25)		0.50 (0.29)	0.38 (0.38)	0.63 (0.13)
S. siderea	3.00 (0.91)	1.25 (0.48)	3.00 (2.04)	3.25 (2.93)	3.00 (0.00)	2.25 (1.00)
S. bournoni				0.50 (0.50)		0.25 (0.25)
Total coral cover	14.00 (4.56)	21.50 (4.63)	5.50 (2.10)	9.00 (2.27)	9.75 (4.25)	15.25 (6.25)
Branching gorgonians	0.25 (0.25)	1.25 (0.48)	0.50 (0.29)	0.50 (0.29)	0.38 (0.13)	0.88 (0.38)
Sponges	6.50 (1.04)	4.25 (0.75)	8.25 (2.39)	6.25 (1.03)	4.13 (2.71)	5.25 (1.00)
Algal turf	30.75 (2.14)	28.50 (2.40)	26.50 (2.40)	19.50 (1.55)	28.63 (2.13)	24.00 (4.50)
Coralline algae	6.25 (1.70)	18.50 (3.43)	8.75 (1.55)	19.50 (2.78)	7.50 (1.25)	19.00 (0.50)
Green foliose algae	0.75 (0.48)	0.25 (0.25)	1.00 (0.71)	0.50 (0.29)	0.88 (0.13)	0.38 (0.13)
Halimeda spp.	4.25 (0.63)	2.75 (0.48)	3.25 (1.03)	3.50 (0.50)	3.75 (0.50)	3.13 (0.38)
Brown foliose algae	11.00 (2.45)	1.75 (0.63)	9.00 (2.27)	8.50 (3.28)	10.00 (1.00)	5.13 (3.38)
Red foliose algae	0.50 (0.29)		0.25 (0.25)		0.38 (0.13)	
Red calcareous algae	0.50 (0.29)			2.00 (0.82)	0.25 (0.25)	1.00 (1.00)
Cyanobacteria	1.75 (0.48)		2.50 (1.66)	0.25 (0.25)	2.13 (0.38)	0.13 (0.13)
Total algal cover	56.75 (1.31)	51.75 (4.33)	51.75 (6.12)	53.75 (5.01)	54.25 (2.50)	52.75 (1.00)
Sand	12.75 (2.63)	15.00 (2.35)	14.00 (2.80)	16.25 (6.07)	13.38 (0.63)	15.63 (0.63)
Sand on hard-bottom	10.25 (3.12)	4.00 (1.47)	19.50 (4.99)	5.50 (1.19)	14.88 (4.63)	4.75 (0.75)

The three most abundant juveniles on experimental and control patch reefs were *Porites astreoides*, *Siderastrea radians*, and *S. siderea*. The size distribution of juvenile *P. astreoides* indicated increases in most size classes, especially colonies < 2.5 cm in maximum diameter (Fig. 7). In contrast, the size distribution of *S. radians* showed little change from year to year or between experimental and control sites (Fig. 8). For *S. siderea*, the decrease in mean juvenile size for both experimental patch reefs was principally due to the greater abundance of smaller juveniles (< 1.5 cm) observed during 2002 (Fig. 9). A similar pattern was observed on CR #3 for this species, but not CR #4. For some of the more common species observed as juveniles, while greater numbers of smaller size classes were observed in 2002 compared to 2001, these changes were magnified on the experimental patch reefs.

Table 9. Mean (1 SE) percent cover of major benthic groups on control patch reefs before and one year after urchin translocation. Sample size = 4 transects per site per year and 100 points per transect.

Bottom type	Control site #3		Control site #4		Combined control	
	2001	2002	2001	2002	2001	2002
A. agaricites	0.50 (0.29)		0.25 (0.25)	0.25 (0.25)	0.38 (0.13)	0.13 (0.13)
A. fragilis				0.25 (0.25)		0.13 (0.13)
C. natans			1.00 (1.00)		0.50 (0.50)	
D. stokesi	0.50 (0.29)	0.50 (0.29)			0.25 (0.18)	0.25 (0.25)
D. labyrinthiformis				1.75 (1.44)		0.88 (0.88)
M. alcicornis	0.50 (0.29)	0.25 (0.25)	0.25 (0.25)	0.25 (0.25)	0.38 (0.13)	0.25 (0.00)
M. cavernosa			6.75 (3.90)	3.25 (3.25)	3.38 (3.38)	1.63 (1.63)
M. faveolata	1.00 (1.00)	1.50 (1.50)			0.50 (0.50)	0.75 (0.75)
M. frankski				0.25 (0.25)		0.13 (0.13)
P. astreoides	1.50 (0.96)	0.75 (0.48)	1.50 (0.50)	0.75 (0.25)	1.50 (0.00)	0.75 (0.00)
P. porites furcata	0.50 (0.29)	0.50 (0.29)	0.25 (0.25)	0.25 (0.25)	0.38 (0.13)	0.38 (0.13)
S. radians		0.50 (0.50)		0.50 (0.29)		0.50 (0.50)
S. siderea	0.25 (0.25)		2.00 (0.71)	1.00 (0.41)	1.13 (0.88)	0.50 (0.50)
S. bournoni	1.25 (1.25)	1.00 (1.00)			0.63 (0.63)	0.50 (0.50)
S. michelini	0.25 (0.25)				0.13 (0.13)	
Total coral cover	6.25 (2.21)	5.00 (2.74)	12.00 (4.45)	8.50 (3.20)	9.13 (2.88)	6.75 (1.75)
Branching gorgonians		1.25 (0.63)	0.25 (0.25)	0.75 (0.25)	0.13 (0.13)	1.00 (0.25)
Sponges	6.75 (1.31)	7.00 (2.12)	3.75 (1.49)	5.00 (0.58)	5.25 (1.50)	6.00 (1.00)
Algal turf	21.50 (4.77)	25.00 (4.22)	25.25 (4.97)	30.50 (2.72)	23.38 (1.88)	27.75 (2.75)
Coralline algae	6.25 (1.65)	9.75 (2.59)	9.25 (2.59)	6.75 (1.31)	7.75 (1.50)	8.25 (1.50)
Green foliose algae	0.25 (0.25)	1.00 (0.41)	1.25 (0.75)		0.13 (0.13)	0.50 (0.50)
Halimeda spp.	2.75 (0.63)	4.75 (1.89)	0.75 (0.48)	2.75 (1.31)	1.75 (1.00)	3.75 (1.00)
Brown foliose algae	6.00 (2.04)	10.75 (2.63)	3.00 (1.78)	1.00 (0.41)	4.50 (1.50)	5.88 (4.88)
Red foliose algae						
Red calcareous algae		2.25 (0.95)				1.13 (1.13)
Cyanobacteria	15.25 (4.66)		5.75 (1.11)	1.00 (0.41)	10.50 (4.75)	0.50 (0.50)
Total algal cover	52.00 (5.99)	53.50 (8.05)	45.25 (5.19)	42.00 (3.49)	48.63 (3.38)	47.75 (5.75)
Sand	21.00 (9.16)	21.25 (9.34)	21.50 (5.52)	29.50 (7.01)	21.25 (0.25)	25.38 (4.13)
Sand on hard-bottom	14.00 (4.34)	7.50 (2.33)	0.50 (0.29)	3.75 (1.80)	7.25 (6.75)	5.63 (1.88)

Discussion

The community structure of coral reefs throughout the Caribbean and in Florida has changed in dramatic ways over the last two decades. The epizootic die-off of the keystone grazer *Diadema antillarum* in the 1980s (Lessios 1988), whiteband disease that killed *Acropora* corals to the point of ecological extinction (Aronson and Precht 2001), possibly nutrification (Lapointe 1997), and overfishing (Hughes et al. 1999), have all contributed to a shift from coral reefs dominated by stony corals to dominance by macroalgae. Because grazing by *D. antillarum* previously had such a profound effect in reducing macroalgae on coral reefs, and because juvenile sea urchins are apparently readily available in select rubble zone habitats in the Florida Keys, we decided to test the efficacy of translocating sea urchins to evaluate survival after translocation and the potential effects of increased grazing on benthic community structure. Two of the experimental patch reefs received over six hundred transplanted urchins during 2001, and despite 70% mortality after one year, densities still averaged approximately 1 urchin/m^2, similar to historical densities reported for the Florida Keys (Kier and Grant 1965; Bauer 1976, 1980). Sources of sea urchin mortality identified during the one-year study included storms (primarily in rubble zone habitats; see previous chapter) and fish predation.

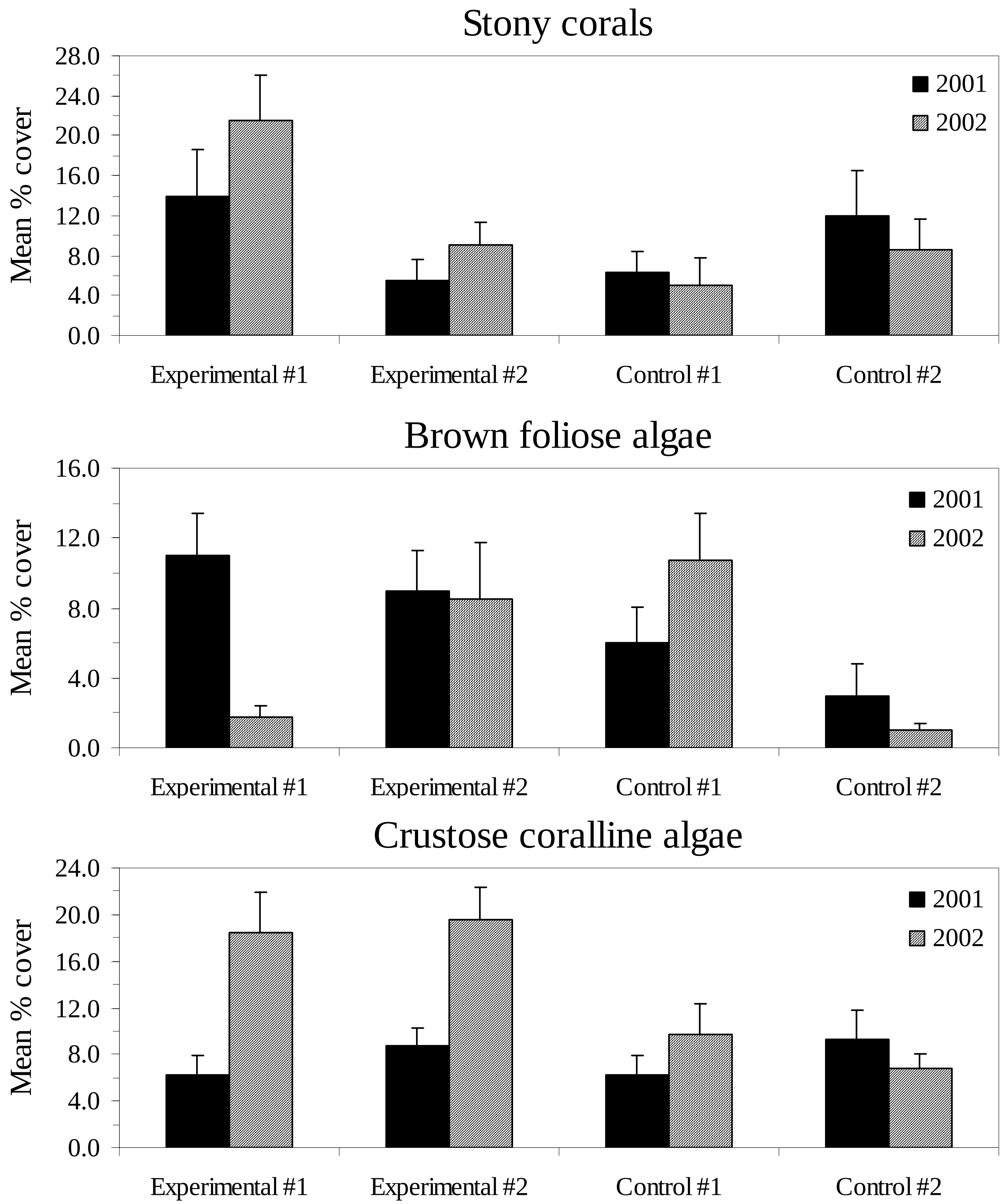


Figure 5. Changes in mean percent cover of stony corals, crustose coralline algae, and brown foliose algae before and one year after urchin translocation on Florida Keys patch reefs. Error bars represent one standard error. “Control #1 and #2” = CR #3 and CR #4.

Table 10. Mean (1 SE) density (no. per m^2) of juvenile scleractinian corals on experimental (top) and control (bottom) patch reefs before and one year after urchin translocation. Sample size = ten 0.65 m x 0.48 m quadrats along each of two transects per site (total area per transect = 3.12 m^2).

Experimental patch reefs

Coral species	Experimental site #1		Experimental site #2		Combined experimental	
	2001	2002	2001	2002	2001	2002
A. agaricites	0.77 (0.24)	0.32 (0.32)		0.32 (0.32)	0.39 (0.39)	0.32 (0.00)
A. fragilis				0.48 (0.48)		0.24 (0.24)
E. fastigiata				0.16 (0.16)		0.08 (0.08)
L. cucullata				0.16 (0.16)		0.08 (0.08)
M. cavernosa			0.32 (0.32)		0.16 (0.16)	
P. astreoides	1.28 (0.32)	2.72 (1.12)	1.76 (0.48)	6.89 (2.08)	1.52 (0.24)	4.81 (2.09)
P. branneri				0.16 (0.16)		0.08 (0.08)
P. porites	0.80 (0.48)	0.32 (0.32)	0.32 (0.00)	1.60 (0.00)	0.56 (0.24)	0.96 (0.64)
S. radians	3.85 (0.96)	4.97 (4.01)	3.04 (0.80)	4.01 (1.44)	3.45 (0.41)	4.49 (0.48)
S. siderea	0.16 (0.16)	4.17 (4.17)	0.32 (0.32)	3.53 (2.88)	0.24 (0.08)	3.85 (0.32)
S. bournoni	0.16 (0.16)	0.32 (0.32)			0.08 (0.08)	0.16 (0.16)
S. michelini		0.16 (0.00)		0.16 (0.16)		0.16 (0.00)
Total density	6.57 (0.80)	13.14 (1.28)	5.77 (0.64)	17.47 (4.01)	6.17 (0.40)	15.31 (2.17)
Total species	6	7	5	10	7	11

Control patch reefs

Coral species	Control site #3		Control site #4		Combined control	
	2001	2002	2001	2002	2001	2002
A. agaricites		0.48 (0.16)	1.92 (0.00)	1.12 (0.80)	0.96 (0.96)	0.80 (0.32)
D. stokesi	0.16 (0.16)			0.16 (0.16)	0.08 (0.08)	0.08 (0.08)
M. cavernosa	0.32 (0.32)	0.16 (0.16)		0.32 (0.00)	0.16 (0.16)	0.24 (0.08)
P. astreoides	2.08 (1.76)	4.17 (0.32)	2.72 (0.48)	3.04 (0.16)	2.40 (0.32)	3.61 (0.57)
P. branneri			0.16 (0.16)		0.08 (0.08)	
P. porites	0.16 (0.16)	0.48 (0.48)		0.64 (0.64)	0.08 (0.08)	0.56 (0.08)
S. radians	2.40 (1.44)	1.92 (0.32)	1.60 (0.32)	1.76 (1.76)	2.00 (0.40)	1.84 (0.08)
S. siderea	0.48 (0.16)	3.53 (0.32)	0.48 (0.16)	1.60 (0.96)	0.48 (0.00)	2.57 (0.97)
S. michelini	0.32 (0.32)	0.32 (0.00)	0.32 (0.32)	0.16 (0.16)	0.32 (0.00)	0.24 (0.08)
Total density	5.93 (0.16)	11.06 (0.48)	7.21 (0.80)	8.81 (2.72)	6.57 (0.64)	9.94 (1.13)
Total species	7	7	6	8	9	8

Previous studies have clearly shown the effects of enhanced or depressed sea urchin densities on coral reef community structure. Experimental reductions of sea urchins on patch reefs on the north coast of Jamaica caused substantial changes in algal biomass, species composition, and coral recruitment (Sammarco 1980), while the mass mortality of *Diadema antillarum* in 1983-84 resulted in marked increases in algal cover, changes in algal species composition, and declines in coral cover and recruitment, especially in shallower reef habitats (Liddell and Ohlhorst 1986; Hughes et al. 1987). Conversely, artificially enhanced or naturally recovering sea urchin populations can cause marked declines in macroalgal abundance and increases in juvenile coral densities (Edmunds and Carpenter 2001; Haley and Solandt 2001; Solandt and Campbell 2001). Not surprisingly, results from our translocation indicate that enhanced sea urchin densities are probably responsible for the changes in algal species composition and abundance and juvenile coral densities recorded, even over the course of only one year. These results are not unexpected, as a number of studies have demonstrated the effects of increased urchin densities on coral reef benthos (Edmunds and Carpenter 2001), or conversely, the effects of the 1983-84 mass mortality of sea urchins on benthic community structure (Hughes et al. 1985; Carpenter 1990). Without sea urchins, fleshy and filamentous algae are abundant and corals are scarce, but with *D. antillarum*, opposing patterns emerge (Woodley 1999a).

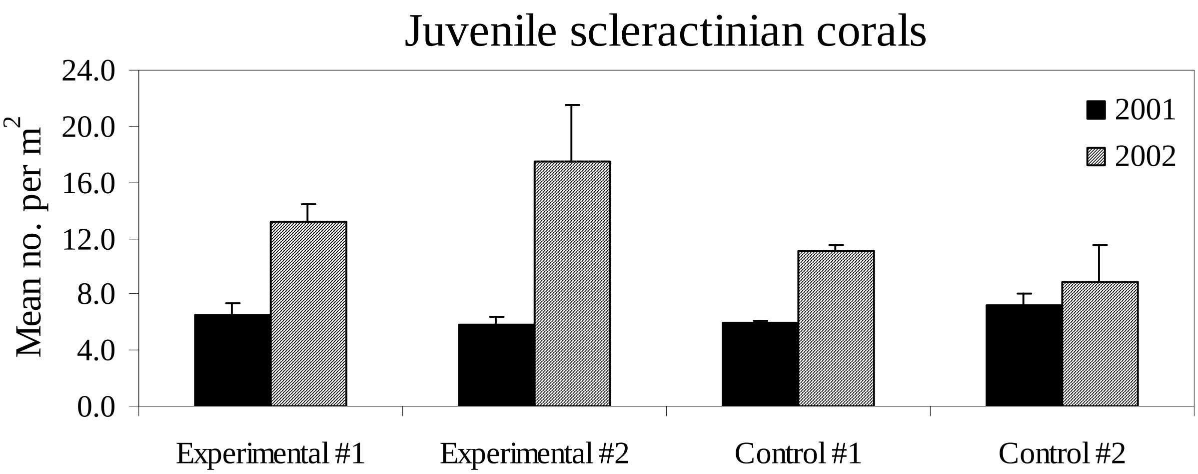


Figure 6. Changes in mean density (no. colonies per m^2) of juvenile scleractinian corals before and one year after urchin translocation on Florida Keys patch reefs. Error bars represent one standard error. "Control #1 and #2" = CR #3 and CR #4.

Table 11. Mean (1 SE) diameter (cm) of juvenile scleractinian corals on experimental (top) and control (bottom) patch reefs before and one year after urchin translocation. N = number of juveniles sampled.

Experimental patch reefs

Coral species	Experimental site #1				Experimental site #2			
	2001		2002		2001		2002	
	N	Mean	N	Mean	N	Mean	N	Mean
A. agaricites	2	2.1 (0.9)	2	2.4 (1.5)			2	2.3 (1.3)
A. fragilis							3	2.8 (0.2)
E. fastigiata							1	0.8 (---)
L. cucullata							1	0.9 (---)
M. cavernosa					2	1.8 (0.9)		
P. astreoides	8	2.2 (0.4)	18	2.0 (0.3)	11	1.8 (0.3)	28	1.4 (0.2)
P. branneri							1	2.7 (---)
P. porites	5	2.7 (0.3)	2	1.5 (0.0)	2	1.5 (0.6)	4	1.8 (0.4)
S. radians	24	2.0 (0.2)	31	1.7 (0.1)	19	1.3 (0.2)	8	1.8 (0.4)
S. siderea	1	2.4 (---)	25	0.8 (0.2)	2	2.1 (0.7)	20	0.8 (0.2)
S. bournoni	1	3.2 (---)	2	2.4 (0.1)				
S. michelini			2	1.0 (0.4)			1	1.3 (---)

Control patch reefs

Coral species	Control site #1				Control site #2			
	2001		2002		2001		2002	
	N	Mean	N	Mean	N	Mean	N	Mean
A. agaricites			3	3.0 (0.4)	12	1.4 (0.3)	7	2.3 (0.2)
D. stokesi	1	2.4 (---)					1	2.4 (---)
M. cavernosa	2	1.0 (0.2)	1	1.7 (---)			2	2.9 (0.7)
P. astreoides	13	2.0 (0.3)	27	1.5 (0.2)	16	1.6 (0.2)	18	1.7 (0.3)
P. branneri					1	1.1 (---)		
P. porites	1	2.4 (---)	3	2.4 (0.9)			4	1.8 (0.7)
S. radians	15	1.8 (0.2)	12	2.4 (0.3)	10	1.5 (0.2)	11	1.7 (0.2)
S. siderea	3	2.7 (0.5)	22	1.1 (0.2)	3	1.8 (0.3)	10	1.2 (0.2)
S. michelini	2	2.5 (0.3)	2	2.7 (1.2)	2	1.7 (0.5)	1	2.9 (---)

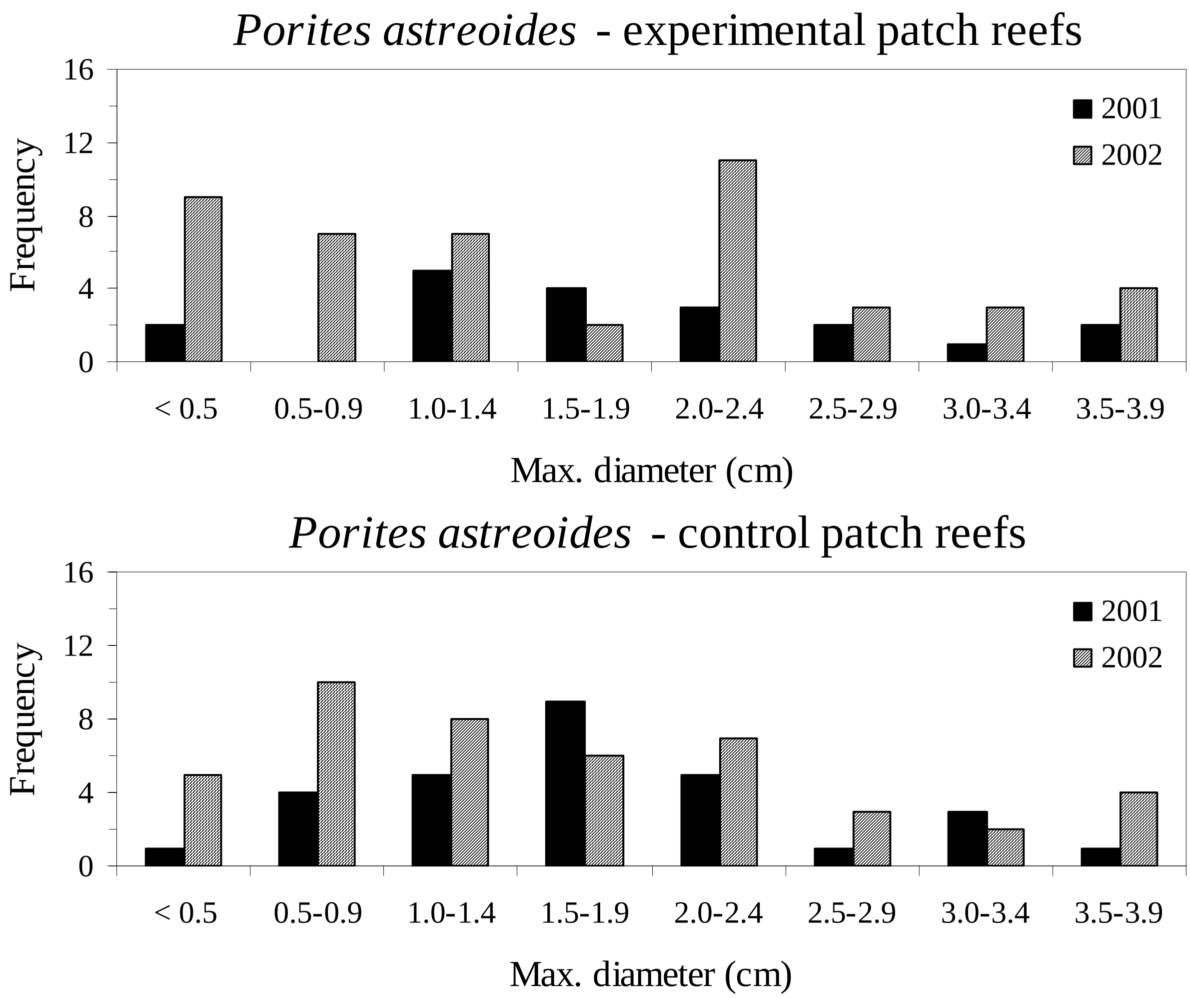


Figure 7. Size frequency distributions of juvenile *Porites astreoides* before and one year after urchin translocation on Florida Keys patch reefs.

Recent studies on the north coast of Jamaica have shown that urchin densities within particular zones are 10 times higher than in adjacent areas and may initiate a phase shift reversal from algal to coral dominance (Edmunds and Carpenter 2001). Within these urchin zones, juvenile coral densities are 2 to 11 times greater than in seaward zones dominated by macroalgae. At low sea urchin densities, macroalgal abundance is high and settlement of coral spat may be high, but survivorship is low due to algal overgrowth. In contrast, at high sea urchin densities, intense grazing may damage juvenile corals and coral survivorship may be reduced (Sammarco 1980). In our translocation study, the increase in the number of species and densities of juvenile corals may be due to two causal mechanisms. First, increased sea urchin grazing and hence a reduction in fleshy macroalgae may facilitate the identification of smaller (< 4 cm) corals within quadrats during 2002, particularly on the experimental sites. Second, increased grazing by urchins could have led to increased coverage by crustose coralline algae, which may enhance coral settlement. For example, lettuce coral larvae of the genus *Agaricia* are induced to metamorphose by crustose coralline algae (Morse et al. 1988) and experimental studies have shown that *A. humilis* settle and metamorphose in response to chemosensory recognition of a morphogen on the surface of the alga *Hydrolithon boergesenii* (Morse et al. 1994). Although juvenile *Agaricia* were not the

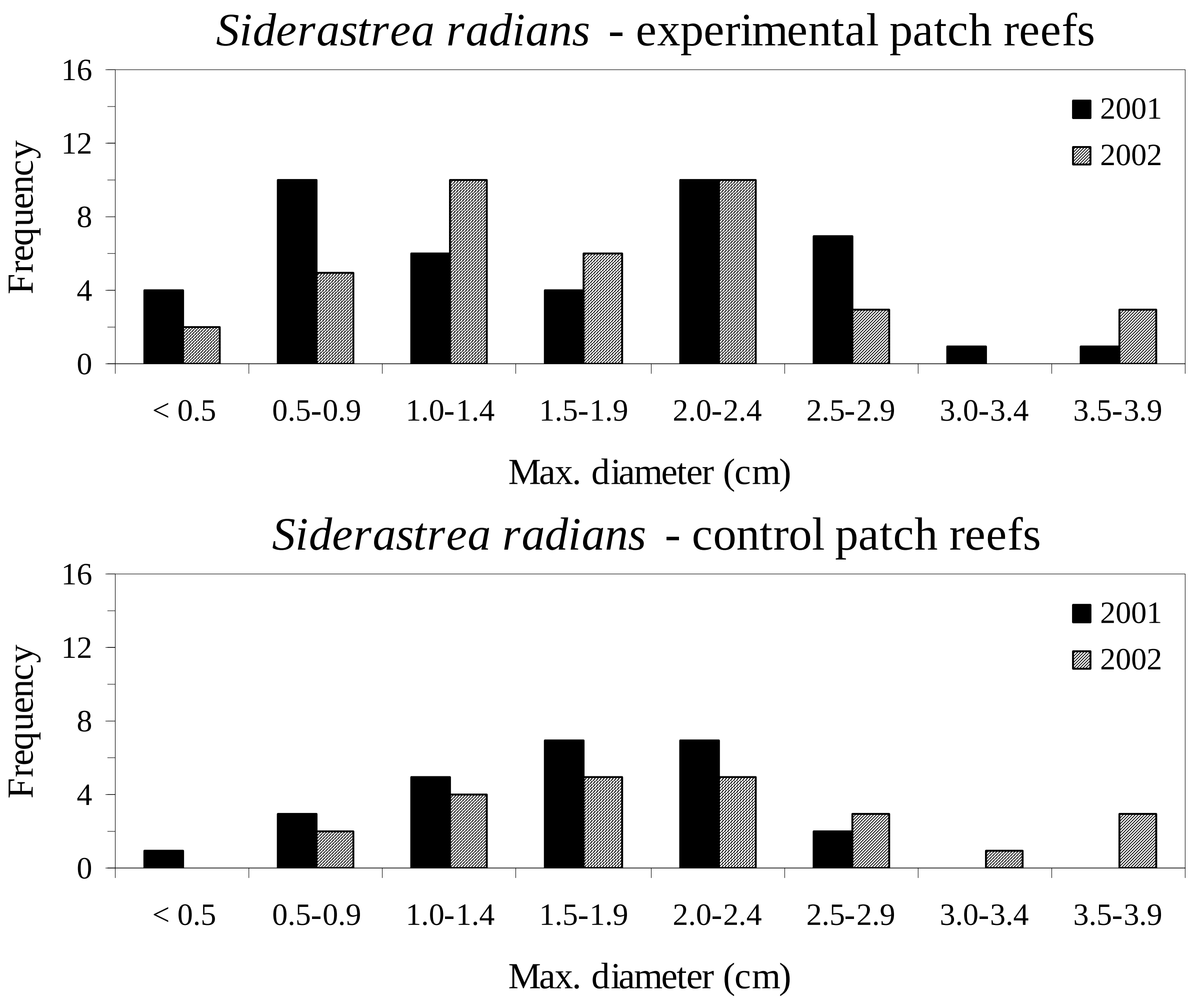


Figure 8. Size frequency distributions of juvenile *Siderastrea radians* before and one year after urchin translocation on Florida Keys patch reefs.

most abundant juveniles on the experimental patch reefs, it was clear that coverage of crustose coralline algae increased on the experimental reefs. However, without knowing the settlement preferences of the most abundant juvenile corals, it is impossible to discern whether increased grazing facilitated our ability to detect small juvenile corals or settlement was enhanced because of reduced algal cover. It is also plausible that a pulse recruitment event or greater post-settlement survivorship occurred for several coral species during the study period, as increases in juvenile densities, especially smaller size classes, were also recorded on the control patch reefs.

It will remain important to monitor these patch reefs during the next one to two years, in order to ascertain the fate of the remaining translocated urchins. If these sea urchins remain for the time being, will changes to the benthos continue, or if they suffer mortality, if and how quickly will the patch reefs return to their previous state? It appears that sea urchin densities of about 1 individual per m^2 were sufficient to cause detectable changes on these patch reefs, even over a relatively short period. While more substantial changes have been recently reported for Jamaican reefs (Edmunds and Carpenter 2001), especially in terms of juvenile coral densities, sea urchin densities are significantly greater than the experimental patch reefs used in our study. Other issues to address concern how much translocation, if any, will be required in other habitat types

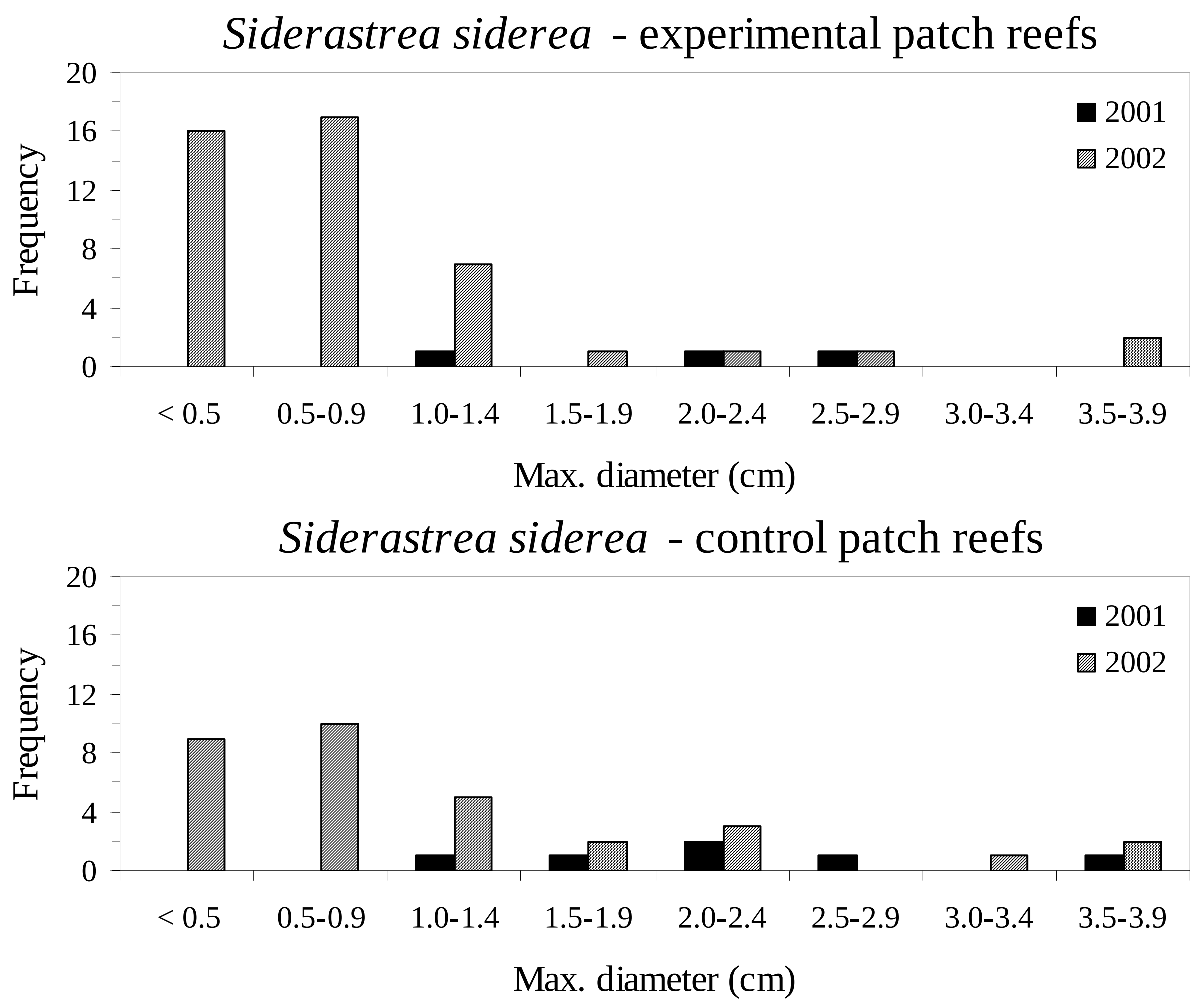


Figure 9. Size frequency distributions of juvenile *Siderastrea siderea* before and one year after urchin translocation on Florida Keys patch reefs.

to maintain densities of approximately one sea urchin per m^2, as well as the principal causes of sea urchin mortality after translocation. It is also possible that juvenile sea urchin settlement may eventually be enhanced by the presence of adult sea urchins on the experimental reefs.

Acknowledgements

The authors would like to thank K. Nedimyer and M. Moe for original program design and the Florida Keys National Marine Sanctuary and Emerson Associates International for funding. B. Keller, O. Rutten, M. Vermeij, The Nature Conservancy, and NOAA's National Undersea Research Center at the University of North Carolina-Wilmington provided logistical support.

Literature Cited

Aronson, R.B., and W.F. Precht. 2001 Evolutionary paleoecology of Caribbean coral reefs. Pages 171-233 *in* W.D. Allmon and D.J. Bottjer, eds. Evolutionary paleoecology: the ecological context of macroevolutionary change. Columbia University Press, NY.

Bauer, J.C. 1976. Growth, aggregation, and maturation in the echinoid, *Diadema antillarum*. Bulletin of Marine Science 26: 273-277.

Bauer, J.C. 1980. Observations on geographic variations in population density of the echinoid *Diadema antillarum* within the western north Atlantic. Bulletin of Marine Science 30: 509-515.

Carpenter, R.C. 1990. Mass mortality of *Diadema antill*arum. I. Long-term effects on sea urchin population-dynamics and coral reef algal communities. Marine Biology 104: 67-77.

Chiappone, M., S.L. Miller, D.W. Swanson, J.S. Ault, and S.G. Smith. 2001. Comparatively high densities of the long-spined sea urchin in the Dry Tortugas, Florida. Coral Reefs 20: 137-138.

Chiappone, M., and K.M. Sullivan. 1997. Rapid assessment of reefs in the Florida Keys: results from a synoptic survey. Proceedings of the 8th International Coral Reef Symposium, Panama, 2: 1509-1514.

Chiappone, M., D.W. Swanson, and S.L. Miller. 2002a. Density, spatial distribution and size structure of sea urchins in coral reef and hard-bottom habitats of the Florida Keys. Marine Ecology Progress Series 235: 117-126.

Chiappone, M., D.W. Swanson, S.L. Miller, and S.G. Smith. 2002b. Large-scale surveys on the Florida Reef Tract indicate poor recovery of the long-spined sea urchin *Diadema antillarum*. Coral Reefs 21: 155-159.

Dustan, P. 1977. Vitality of reef coral populations off Key Largo, Florida: recruitment and mortality. Environmental Geology 2: 51-58

Dustan, P., and J.C. Halas. 1987. Changes in the reef-coral community of Carysfort Reef, Key Largo, Florida: 1974 to 1982. Coral Reefs 6: 91-106.

Edmunds, P.J., and R.C. Carpenter. 2001. Recovery of *Diadema antillarum* reduces macroalgal cover and increases abundance of juvenile corals on a Caribbean reef. Proceedings of the National Academy of Sciences 98: 5067-5071.

Forcucci, D. 1994. Population density, recruitment and 1991 mortality event of *Diadema antillarum* in the Florida Keys. Bulletin of Marine Science 54: 917-928.

Haley, M.P., and J.L. Solandt. 2001. Population fluctuations of the sea urchins *Diadema antillarum* and *Tripneustes ventricosus* at Discovery Bay, Jamaica: a case of biological succession? Caribbean Journal of Science 37:239-245.

Hallock, P., F.E. Muller-Karger, and J.C. Halas. 1993. Coral reef decline: anthropogenic nutrients and the degradation of western Atlantic and Caribbean coral reefs. National Geographic Research & Exploration 9: 358-378.

Hay, M.E. 1984. Patterns of fish and urchin grazing on Caribbean coral reefs: are previous results typical? Ecology 65: 446-454.

Hughes, T.P., and J.H. Connell. 1999. Multiple stressors on coral reefs: a long-term perspective. Limnology and Oceanography 44: 932-940.

Hughes, T.P., B.D. Keller, J.B.C. Jackson, and M.J. Boyle. 1985. Mass mortality of the echinoid *Diadema antillarum* Philippi in Jamaica. Bulletin of Marine Science 36: 377-384.

Hughes, T.P., D.C. Reed, and M. Boyle. 1987. Herbivory on coral reefs: community structure following mass mortalities of sea urchins. Journal of Experimental Marine Biology and Ecology 113: 39-59.

Hughes, T.P., A.M. Szmant, R. Steneck, R. Carpenter, and S. Miller. 1999. Algal blooms on coral reefs: what are the causes? Limnology and Oceanography 44: 1583-1586.

Hunte, W., I. Cote, and T. Tomascik. 1986. On the dynamics of the mass mortality of *Diadema antillarum* in Barbados. Coral Reefs 4: 135-139.

Jaap, W.C. 1984. The ecology of the south Florida coral reefs: a community profile. U.S. Fish Wildl. Serv., Office Biol. Serv., Washington, DC, FWS/OBS-82/08.

Jaap, W.C., J.C. Halas, and R.G. Muller. 1988. Community dynamics of stony corals (Scleractinia and Milleporina) at Key Largo National Marine Sanctuary, Key Largo, Florida during 1981-1986. Proceedings of the 6th International Coral Reef Symposium, Townsville, 2: 237-243.

Kier, P.M., and R.E. Grant. 1965. Echinoid distribution and habits, Key Largo Coral Reef Preserve, Florida. Smithsonian Miscellaneous Collections 149: 1-68.

Lapointe, B.E. 1989. Caribbean coral reefs: are they becoming algal reefs? Sea Frontiers (March-April): 83-91.

Lapointe, B.E. 1997. Nutrient thresholds for eutrophication and macroalgal blooms on coral reefs in Jamaica and southeast Florida. Limnology and Oceanography 42: 1119-1131.

Lessios, H.A. 1988. Mass mortality of *Diadema antillarum* in the Caribbean: what have we learned? Annual Review of Ecology and Systematics 19: 371-393.

Lessios, H.A., D.R. Robertson, and J.D. Cubit. 1984. Spread of *Diadema* mass mortality through the Caribbean. Science 226: 335-337.

Liddell, W.D., and S.L. Ohlhorst. 1986. Changes in benthic community composition following the mass mortality of *Diadema* at Jamaica. Journal of Experimental Marine Biology and Ecology 95: 271-278.

Marszalek, D.S., G. Babashoff, M.R. Noel, and D.R. Worley. 1977. Reef distribution in south Florida. Proceedings of the 3rd International Coral Reef Symposium, Miami, 2: 223-229.

Miller, S.L., D.W. Swanson, and M.Chiappone. 2002. Multiple spatial scale assessment of coral reef and hardbottom community structure in the Florida Keys National Marine Sanctuary. Proceedings of the 9th International Coral Reef Symposium 1: 69-74.

Morse, D.E., N. Hooker, A.N.C. Morse, and R.A. Jensen. 1988. Control of larval metamorphosis and recruitment in sympatric agariciid corals. Journal of Experimental Marine Biology and Ecology 116: 193-217.

Morse, D.E., A.N.C. Morse, P.T. Raimondi, and N. Hooker. 1994. Morphogen-based chemical flypaper for *Agaricia humilis* coral larvae. Biological Bulletin 186: 172-181.

Moses, C.S., and R.M Bonem. 2001. Recent population dynamics of *Diadema antillarum* and *Tripneustes ventricosus* along the north coast of Jamaica, W.I. Bulletin of Marine Science 68: 327-336.

Porter, J.W., and O.W. Meier. 1992. Quantification of loss and change in Floridian reef coral populations. American Zoologist 32: 625-640.

Richardson, L.L., W.M. Goldberg, R.G. Carlton, and J.C. Halas. 1998. Coral disease outbreak in the Florida Keys: plague type II. Revista de Biologia Tropical 46: 187-198.

Roberts, H.H., L.J. Rouse, N.D. Walker, and J.H. Hudson. 1982. Cold-water stress in Florida Bay and northern Bahamas: a product of winter cold-air outbreaks. Journal of Sedimentary Petrology 52: 145-155.

Sammarco, P.W. 1980. *Diadema* and its relationship to coral spat mortality, grazing, competition, and biological disturbance. Journal of Experimental Marine Biology and Ecology 45: 245-272.

Sammarco, P.W., J.S. Levinton, and J.C. Ogden. 1974. Grazing and control of coral reef community structure by *Diadema antillarum* Philippi (Echinodermata: Echinoidea): a preliminary study. Journal of Marine Research 32: 47-53.

Santavy, D.L., E. Mueller, E.C. Peters, L. MacLaughlin, J.W. Porter, K.L. Patterson, and J. Campbell. 2001. Quantitative assessment of coral diseases in the Florida Keys: strategy and methodology. Hydrobiologia 460: 39-52.

Solandt J., and A.C. Campbell. 2001. Macroalgal feeding characteristics of the sea urchin *Diadema antillarum* Philippi at Discovery Bay, Jamaica. Caribbean Journal of Science 37: 227-238.

Woodley, J.D. 1999a. Sea-urchins exert top-down control of macroalgae on Jamaican coral reefs (1). Coral Reefs 18: 192.

Woodley, J.D. 1999b. Sea-urchins exert top-down control of macroalgae on Jamaican coral reefs (2). Coral Reefs 18: 192.

Permitted Research Projects

Research Permits Issued by the Florida Keys National Marine Sanctuary: 2002

Information included below: Name of principal investigator and contact information, permit number and duration, project title, project summary, and funding source (if provided).

1) Greta Aeby, U.S. Environmental Protection Agency, Gulf Ecology Division (greta@hawaii.edu). FKNMS-2001-001, 1/8/2001 to 3/1/2002 and FKNMS-2002-057, 7/8/2002-12/31/2002 (fish predation component). Effect of Fish Predation on the Health of Corals in the Florida Keys and the Relationship between Increased Levels of MAAs and Protection from UV Stress in Perforate and Imperforate Corals. This project will examine two potential ways in which coral-feeding fish might be affecting the health of corals in the Florida Keys. The role of fish as transmission vectors of black band disease and the affect of fish predation on the tolerance of corals to increased water temperature and UV stress will both be examined. The amended research will test whether there is a relationship between increased MAAs in corals and subsequent protection from UV damage. The MAA content of coral pieces will be manipulated to obtain one group of coral with a high MAA content and one group with a low MAA content. The bleaching response of the two groups of coral when exposed to UV will then be compared. Both perforate (*Porites porites*) and imperforate (*Madracis mirabilis*) corals will be used for these experiments. Science Training in Ecology Program (STEP) a joint cooperation between the U.S. EPA and the Center for Environmental Diagnostics and Bioremediation (UWF).

2) Susan Anderson, University of California at Davis, Bodega Marine Laboratory (susanderson@ucdavis.edu). FKNMS-2001-024, 5/1/2001 to 4/30/2002. UV Effects and Coral Bleaching. We will evaluate the role that climate change may play in altering penetrance of UV radiation over coral reefs and potentially contributing to coral bleaching. In this study, we have combined the investigation of the molecular effects of UV on corals with a remote sensing component. Funding unknown, assume same as previous permit (FKNMS-99-046), which is EPA, NOAA, and NASA that was funded for three years, through 2002.

3) Andrew Baker, Wildlife Conservation Society and Columbia University (abaker@wcs.org). FKNMS-2002-073, 9/23/2002 to 8/31/2003. Symbiont Distributions in Reef Corals as Indicators of Recent Environmental History. This research uses molecular techniques to identify the dinoflagellate symbionts (*Symbiodinium* spp.) of reef-building corals from the Florida Keys reef tract (and the National Marine Sanctuary in particular). It tests for differences in the distribution of symbionts that correlate with environment, and tests the stability of these distributions by transplanting coral colonies between different environments, with and without exposure to a bleaching stimulus. National Undersea Research Program, UNCW.

4) Iliana Baums, University of Miami, Rosenstiel School of Marine and Atmospheric Science/MBF (ibaums@rsmas.miami.edu). FKNMS-2001-009, 3/12/2001 to 12/31/2002. Genetic Status of *Acropora palmata* Populations in the Caribbean. This project will contribute to the status review of Candidate species (under the Endangered Species Act) *Acropora palmata*, by addressing questions relating to species life history and ecology, as well as population status, history and trends. Specifically, we seek to determine the genotypic diversity within local populations of this coral, and the extent to which geographically isolated populations are

genetically similar, information that will be essential for future conservation and recovery efforts. These findings will aid in assessing the degree of genetic bottleneck that already threatens *A. palmata* recovery and the potential for natural dispersal to repopulate areas of extirpation. NOAA NMFS Candidate Species Program, Project #CP-01-SEC02.

5) Carole Bewley, National Institutes of Health (cb194k@nih.gov). FKNMS-2002-069, 10/14/2002 to 12/31/2004. Investigations of Carbohydrate-Binding Proteins from Marine Cyanobacteria. Collect cyanobacteria samples from subtropical waters and investigate the presence of carbohydrate binding proteins. If such proteins are present, we will determine their optimal ligands and the source of their natural receptors using biochemical and chemical techniques. National Institutes of Health.

6) Gregory Bodnar, Marine Resources Development Foundation (gbodnar@hotmail.com). FKNMS-2001-070, 9/17/2001 to 9/30/2002. Implementation of Permanent Research Stakes within the FKNMS to Conduct ReefCheck Methodology. Permanent stakes will be installed at Grecian Dry Rocks and Molasses Reef for monthly data collection using the ReefCheck protocols. Systematic data collection of benthic substrate, fish and invertebrate diversity and abundance will be collected using this non-invasive, tested methodology. Marine Resources Development Foundation.

7) James Bohnsack, National Marine Fisheries Service, Southeast Fisheries Science Center (jim.bohnsack@noaa.gov). FKNMS-2000-031, 5/15/2000 to 12/31/2002. Non-destructive Visual Census of Reef Fish Populations in the Florida Keys. This research is part of an ongoing project to assess reef fish populations of the Florida Keys, from Fowey Rocks to the Dry Tortugas. This project is also part of the Sanctuary's Marine Zone Monitoring Program to assess reef fish changes inside and outside fully protected zones. NMFS; NURC support for paired benthic & fisheries assessments in Dry Tortugas. [Summary of findings in annual report]

8) Jill Borger, University of Miami, Rosenstiel School for Marine and Atmospheric Sciences (jborger@rsmas.miami.edu). FKNMS-2001-074, 10/17/2001 to 10/16/2001 and FKNMS-2002-064, 11/27/2002 to 12/31/2003. Coral Disease Ecology and the Effects of Disease on Reproduction. This project is an extension of work begun last year. The permit will cover two projects; the first involves a detailed examination of specific reef sites in order to follow the specific incidence, movement and transmission of coral diseases over time. This will involve non-destructive sampling methods, such as transect lines and quadrats, and detailed maps of each site will be constructed. The second project will examine the effects of disease on coral reproduction. A few samples will be taken from both diseased and healthy colonies and total fecundity, or reproductive output, will be measured histologically. The fecundity values for diseased and healthy colonies will be compared and analyzed. Reitmeister Award and anonymous donation to Jill Borger.

9) Joan Browder, NOAA/National Marine Fisheries Service (joan.browder@noaa.gov). FKNMS-2002-002, 1/3/2002 to 12/31/2003. Post-larval Sampling Project. The purpose of the sampling project is to describe spatial and temporal patterns of postlarval pink shrimp immigration to potential nursery grounds in Florida Bay from offshore spawning grounds. Accessibility of potential nursery grounds to pink shrimp postlarvae (i.e., postlarval ingress rate)

may be an important factor limiting the Bay's capacity to produce pink shrimp recruits to the Tortugas fishing grounds. NOAA/NMFS Southeast Fisheries Science Center.

10) Michael Burton, NOAA/National Marine Fisheries Service (michael.burton@noaa.gov). FKNMS-2002-034, 5/8/2002 to 3/31/2003. Biological Characterization of Riley's Hump and Identification of Spawning Areas. Visual census transects (SCUBA) will be used to quantify mutton snapper abundance in the vicinity of Riley's Hump and compare it to baseline data. Habitat will be characterized by divers using 0.5 m^2 quadrats. NOAA/NMFS Coral Reef Initiative.

11) Mark Butler, Old Dominion University (mbutler@odu.edu). FKNMS-2002-043, 6/5/2002 to 6/4/2003. Characterization of Hardbottom Community Dynamics: Sponges, Octocorals, Lobsters, & Octopus. My research team is currently working on several related projects involving the shallow, hard-bottom communities so common throughout the Florida Keys. In some cases, our research is focused on the ecology of single species of specific ecological or economic importance (e.g., spiny lobster, commercial sponges, octopus). In other cases, our research involves community-level assessment and the influence of environmental (e.g., salinity change) or human factors (e.g., fishing) on the structure of hard-bottom communities over large spatial scales. In both cases, we use a combination of field sampling, field and laboratory experimentation, and computer simulation modeling to test hypotheses of interest. National Science Foundation, OCE-0136894 and NOAA Coastal Ocean Program.

12) Roy Caldwell, University of California, Berkeley (4roy@socrates.berkeley.edu). FKNMS-2002-062, 10/18/2002 to 12/31/2003. The Biology of Stomatopod Crustaceans. This proposal focuses on stomatopod crustaceans, asking basic biological questions about their distribution and abundance, reproductive behavior, larval dispersal, and how they communicate in a colorful underwater world. NOAA/National Undersea Research Center, Key Largo.

13) Mary Alice Coffroth, State University of New York at Buffalo (coffroth@buffalo.edu). FKNMS-2000-029, 5/1/2000 to 2/28/2002. Reef Connectivity: A Study of Larval Supply and Source of Recruits to the Florida Keys and the Flower Garden Banks. The level of local dispersal and source of coral recruits to the Florida Keys and the Flower Garden Banks will be examined in order to assess reef interdependence or connectivity. In this study the population genetic structure of coral at two sites that vary in their potential for genetic exchange (i.e., Florida Keys and Flower Garden Banks) will be used to infer present (or recent) gene flow patterns in two scleractinian corals, the broadcasting species *Montastraea cavernosa* and the brooding species *Porites astreoides*. NURC supported.

14) Mary Alice Coffroth, State University of New York at Buffalo (coffroth@buffalo.edu). FKNMS-2002-011, 3/4/2002 to 6/30/2004. A Study of Population Dynamics of Scleractinians on Conch Reef: A Demographic and Population Genetics Approach. In this study the influence of recruitment in establishing species composition of reefs will be examined using a combined demographic and population genetic approach to record the species composition at two sites on Conch Reef in the Florida Keys. NOAA/National Undersea Research Center.

15) Felicia Coleman, Florida State University (coleman@bio.fsu.edu). FKNMS-2001-005, 2/23/2001 to 2/28/2003. Studies in the Ecology of Red Grouper, *Epinephelus morio*, including their Contribution to Habitat Heterogeneity and Community Structure. The aim of this project is to examine the structure and function of the community of organisms that take up residence in holes occupied by red grouper. These holes, for the most part, appear to be excavated and maintained by red grouper. The resultant communities are rich in sessile invertebrates and various species of cleaning fish. Marine Conservation Biology Institute, SeaGrant, and Environmental Defense.

16) Carrollyn Cox, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute (carrollyn.cox@fwc.state.fl.us). FKNMS-2001-022, 4/23/2001 to 12/31/2002. Spiny Lobster Spawning Potential and Population Assessment: A Monitoring Program for the South Florida Fishing Region. The proposed study is part of the Sanctuary's Marine Zone Monitoring Program and seeks to investigate the effects of no-take management on this important fishery resource. FMRI. [Summary of findings in annual report]

17) Kerry Davies, Florida State University (davies@bio.fsu.edu). FKNMS-2001-066, 8/29/2001 to 9/1/2002. The Identification and Characterization of Bacterial Flora Associated with Spiny Lobsters in the Florida Keys and the Etiology of Shell Disease in the Caribbean Spiny Lobster, *Panulirus argus*. The purpose of this project is to isolate and identify culturable bacterial flora associated with crustaceans (specifically, spiny lobsters), sediment, and seawater in the Florida Keys. The aim is to isolate and identify microorganisms that may be specifically associated with the shell of spiny lobsters in an effort to determine the ecological significance of crustacean associated bacterial flora and its possible role in shell disease related symptoms. FSU/Reeves.

18) Alan Duckworth, Harbor Branch Oceanographic Institution (aduckworth@hboi.edu). FKNMS-2001-049, 7/23/2001 to 9/30/2003. Aquaculture of the Sponge *Forcepia* sp. for the Sustainable Supply of Bioactive Metabolites for Biomedical Research. The sponge *Forcepia* sp. will be farmed for 1 year at a depth of 20-25m near Tennessee Reef to determine if in situ aquaculture can supply sufficient and sustainable quantities of the metabolites lasonolides for biomedical research. The farmed sponges will be harvested at different rates to examine whether regular tissue harvesting can increase overall yield of lasonolide metabolite. Sponges will be farmed in mesh arrays, which will be either pegged flat to the substrate or held upright in the water column. One array will be maintained beyond the 1-year period and will be used as a supply for ongoing, grant-funded research on the lasonolides. HBOI.

19) Peter Edmunds, California State University at Northridge (peter.edmunds@csun.edu). FKNMS-2002-021, 6/1/2002 to 12/31/2003. Global Climate Change and Coral Recruitment: The Interactive Effects of Temperature and Ontogeny on the Biology of *Porites astreoides* Larvae. The goal of this project is to carry out a multidisciplinary analysis of the biology, physiology and genetics of coral larvae in order to understand how global climate change will affect the coral population structure of reefs such as those in the Florida Keys. NOAA/National Undersea Research Center.

20) David Eggleston, North Carolina State University (eggleston@ncsu.edu). FKNMS-2002-061, 7/2/2002 to 12/31/2003. Fish and Caribbean Spiny Lobster Distribution and Abundance in

the Great White Heron National Wildlife Refuge: An Initial Assessment and Comparison with the Key West National Wildlife Refuge. We will use aerial photographs, ground-truthing and GIS computer software to identify and map habitats within the GWHNWR within which to quantify fish and Caribbean spiny lobster. We will use visual surveys conducted by SCUBA divers to quantify fish and lobster, as well as measure specific habitat characteristics. The study will provide baseline data and be used to make research and management recommendations. Grant from The Ocean Conservancy and U.S. Fish and Wildlife Service.

21) Craig Faunce, Audubon of Florida (cfaunce@audubon.org). FKNMS-2001-064, 9/1/2001 to 9/30/2002. Fish Utilization of Mangrove Fringe Habitats in Southeastern Florida. Our research will evaluate the hypothesis that coastal mangrove communities in tropical and subtropical ecosystems directly and indirectly increase the resilience of exploited reef and other fishes by providing critical habitat for juvenile and sub-adult stages. Awards/grants from NOAA/NMFS Coral Reef Initiative, EDF, and USGS.

22) Bill Fitt, University of Georgia, Institute of Ecology (fitt@sparrow.ecology.uga.edu). FKNMS-2001-007, 3/8/2001 to 12/31/2002. Long Term Monitoring of Tissue Biomass from Five Species of Reef Corals. This project is a continuation of a seasonal monitoring program designed to document the relative physiological health of coral tissue and zooxanthellae for five major coral species in the Keys. Tissue biomass, levels of proteins, carbohydrates and lipids, C:H:N analysis and zooxanthellae photosynthetic potential, densities and chlorophyll content will be determined every 2-3 months for five species of corals living on the Florida Reef Tract. Former support of National Undersea Research Center and University of Georgia. We will be applying to NSF this year to fund the long-term work.

23) Bill Fitt, University of Georgia, Institute of Ecology (fitt@sparrow.ecology.uga.edu). FKNMS-2001-063, 8/27/2001 to /1/2003. Potential for *Acropora cervicornis* (staghorn coral) and *Acropora palmata* (elkhorn coral) in Coral Reef Restoration: Genetics, Physiology, and Growth. This proposal addresses two major issues concerning populations of *A. cervicornis* and *A. palmata* in the Caribbean: the genetic structure and diversity, and some basic questions concerning transplantation. We will compare populations of both species from two locations: relatively pristine reefs (low human impact) near the Caribbean Marine Research Center on Lee Stocking Island in the Bahamas vs. relatively high human impact sites in the Florida Keys National Marine Sanctuary. NOAA/National Undersea Research Center.

24) Nicole Fogarty, The Nature Conservancy (nfogarty@tnc.org). FKNMS-2001-012, 4/1/2001 to 12/31/2002. Sea Stewards Monitoring Program. The Sea Stewards program is part of the Sanctuary's Level III Monitoring program. Volunteers are recruited to provide long-term monitoring of the Sanctuary Preservation Areas and associated reference sites. [Summary of findings in annual report]

25) Mark Fonseca, NOAA/Center for Coastal Fisheries and Habitat Research (CCFHR) (mark.fonseca@noaa.gov). FKNMS-2001-023, 5/1/2001 to 6/30/2003. Effects of Crab/Lobster Traps to Seagrass Beds of the Florida Keys National Marine Sanctuary (FKNMS): Damage Assessment and Evaluation of Long-Term Recovery. This project will assess the effect (if any) of stationary fishing gear (i.e. crab/lobster traps) to seagrass beds of the FKNMS. Replicate traps

will be randomly placed within randomly selected seagrass beds of varying species composition. Intermittent removal of traps will determine the time it takes to sustain injury to the beds. Injury recovery will be tracked quarterly to semi-annually over the following two years. NOS and NMFS.

26) Mark Fonseca, NOAA/Center for Coastal Fisheries and Habitat Research (CCFHR) (mark.fonseca@noaa.gov). FKNMS-2001-029, 6/11/2001 to 6/30/2003. A Novel Technique for the Restoration of Seagrass Propeller Scars: Does Deployment of Sediment-filled, Biodegradable Fabric Tubes in Propeller Scars Enhance Seagrass Regrowth into These Injured Areas? This project will assess the effectiveness of a new method for propeller scar restoration in the FKNMS. Fabric tubes and bird stakes will be deployed into existing propeller scars in a replicated experiment. Intermittent monitoring of treatments will be tracked quarterly to semi-annually over the following two years. NOS.

27) Mark Fonseca, NOAA/Center for Coastal Fisheries and Habitat Research (CCFHR) (mark.fonseca@noaa.gov). FKNMS-2002-009, 2/15/2002 to 12/31/2003. Characterization and Analysis of Seagrass Injury and Recovery on Shallow Seagrass-Coral Banks in the FKNMS. The objectives of this study are to develop a comprehensive database of the complete range of injury categories and the widest possible range of injury ages and species combinations to be modeled in the Habitat Equivalency Analysis. In addition to these detailed injury sites, we will characterize the current conditions on the entire Red Bay bank system using 1/9600 scale vertical aerial photography integrated with differential global positioning system based ground surveys. We will conduct a replicated experiment to determine the effect of excavation depth on the recovery rate of injured *Thalassia testudinum* meadows. We hypothesize that the severity of injuries to a *Thalassia* meadow will be a function of the depth of sediment excavated by the disturbance. NOAA/National Ocean Service/Office of Coastal Resource Management and National Centers for Coastal Ocean Science/CCFHR. [Summary of findings in annual report]

28) James Fourqurean, Florida International University (fourqure@fiu.edu). FKNMS-2001-035, 8/2/2001 to 12/31/2002. Seagrass Monitoring in the Florida Keys National Marine Sanctuary. This project will provide baseline data on the status, species composition, and distribution of seagrass communities within two of the Sanctuary no-take zones, as well as other sites throughout the Sanctuary. This project is part of the FKNMS and EPA Water Quality Protection Program. U.S. EPA/WQPP, FIU. [Summary of findings in annual report]

29) Robert Glazer, Florida Marine Research Institute, Florida Fish and Wildlife Conservation Commission (bob.glazer@fwc.state.fl.us). FKNMS-2001-055, 8/2/2001 to 8/31/2003. Survey and Rehabilitation of Queen Conch within the Florida Keys National Marine Sanctuary. The surveys include visual surveys of sites where conch are sparse, belt-transects of densely populated conch aggregations in offshore reef flats, tag-recapture sampling of nearshore conch aggregations, and sonic tagging experiments. Many of these surveys will be conducted within the Sanctuary Preservation Areas of the Florida Keys National Marine Sanctuary and are conducted as part of the marine zone monitoring surveys. The secondary goal of this research is to determine the spatial and temporal distribution of queen conch larvae in and around the different regions of the Florida Keys. This information will lead to determining the optimal release location of hatchery-reared or transplanted queen conch based upon the probability that conch

larvae spawned in that location will recolonize the Keys. FMRI/FWC. [Summary of findings in annual report]

30) Robert Glazer, Florida Marine Research Institute, Florida Fish and Wildlife Conservation Commission (bob.glazer@fwc.state.fl.us). FKNMS-2001-056, 8/7/2001 to 8/31/2002. Transplantation of Wild Queen Conch from the Nearshore Zone to Offshore Spawning Aggregations: A Strategy for Restoring Florida's Conch Population. The goal of this project is to evaluate the efficacy of a large-scale transplantation program designed to restore the local queen conch spawning population. We will also assess the ecological impacts of a large-scale transplantation program. To meet these objectives, we will transplant juvenile and adult conch from nearshore areas where conch do not spawn to the offshore zone where spawning aggregations are located. Previous studies have shown that conch transplanted from the nearshore zone to offshore recover their reproductive capabilities. U.S. Fish and Wildlife Service, Partnerships for Wildlife Grant.

31) Walter Goldberg, Florida International University (goldberg@fiu.edu). FKNMS-2001-061, 9/1/2001 to 8/31/2002 and FKNMS-2001-067, 8/29/2001 to 9/1/2003. Ultrastructure of Aggression in Corals of the Genus *Mycetophyllia*. This project will test the hypothesis that specialized regions occur at the tip of *Mycetophyllia lamarckiana* or *M. ferox* mesenterial filaments and are used during aggressive behavior. FIU.

32) Dale Griffin, U.S. Geological Survey, Center for Coastal and Regional Marine Studies. FKNMS-2002-058, 6/27/2002 to 7/31/2002. Microbial Water Quality in Nearshore and Offshore Sites in the Florida Keys. Sediments, coral mucus, and the water column will be screened for the presence of microbial fecal indicators in nearshore and offshore waters in the Florida Keys. Mucus from diseased and healthy corals of the same species will be utilized to create a microbial community DNA fingerprint that may allow the identification of the disease-causing pathogen. USGS, University of Georgia.

33) Pamela Hallock Muller, University of South Florida (pmuller@marine.usf.edu). FKNMS-2000-011, 3/2/2000 to 12/31/2002. Long-term Monitoring of Stress in Reef-Dwelling Foraminifera. The reef-dwelling foraminifera, *Amphistegina gibbosa*, have exhibited bleaching and associated symptoms on Florida Keys reefs since summer of 1991. This project will continue long-term monitoring of populations at Conch and Tennessee Reefs, will compare symbiont taxa within *A. gibbosa* between these reefs, and will collect solar insolation data using long-term deployable radiometers. USEPA-ORD-NCERQA grant, 10/1/97 - 9/30/2000 (1 year no-cost extension will be requested). Amendment #2 work done in conjunction with Cheryl Woodley of NOAA and is funded by South Carolina Sea Grant.

34) Heather Ann Halter, Nova Southeastern University, National Coral Reef Institute (NCRI), (heatherhalter@angelfire.com). FKNMS-2001-077, 12/1/2001 to 9/30/2002. Comparison of Spatial, Seasonal and Substrate Changes of Net Carbonate Accumulation on Three South Florida Coral Reef Sites. The goal of this study is to differentiate short-term net carbonate accretion/erosion in Ft. Lauderdale versus the Florida Keys according to three variables: location, season, and substrate type. Carbonate tiles will be placed on the hard bottom at two

different depths at three sites: two in Ft. Lauderdale and one in the Florida Keys, the Tennessee Reef Research-Only Area. NSU Thesis Tuition Reimbursement.

35) M. Dennis Hanisak, Harbor Branch Oceanographic Institution (hanisak@hboi.edu). FKNMS-2000-058, 9/1/2000 to 9/30/2002. Long-term Monitoring of Benthic Algal Communities at the *Wellwood* Grounding Site, Molasses Reef, FKNMS. The grounding of the freighter *M/V Wellwood* on Molasses Reef in August 1984 was a catastrophe of unprecedented proportion in the Sanctuary (the damaged area was 4,865 m^2, with the most severe damage in a flattened area of 1500 m^2). Previously, this research team monitored recolonization of the benthic reef community, with major emphasis on algae, at the *Wellwood* site on Molasses Reef for four years (1985-88) after the grounding and did additional monitoring 10 years later (1995-96). The proposed sampling will extend the database previously obtained, which has application, both in terms of reef recovery after physical disturbance, but also to document long-term changes in the benthic algal community that appear to be occurring at this site. Limited resources required are being provided by HBOI.

36) Clay Harris, Middle Tennessee State University (cdharris@mtsu.edu). FKNMS-2001-041, 7/5/2001 to 10/31/2002. The Wreck of the El Lerri: Is One of America's Oldest "Artificial Reefs" Functioning Ecologically as a Patch Reef or a Hard Bottom Community? We propose to perform a survey of attached benthic inhabitants (coral, sponge, and algae) at (1) a ballast pile (i.e. artificial reef), (2) two patch reef sites (PRS-1 & PRS-2), and (3) two hard-bottom communities (HBS-1 & HBS-2) -- all within 0.25 to1.5 nautical miles of shore on the ocean side of Lower Matecumbe and Craig Keys. At each of the five sites we will lay out two 25-m transects of contiguous 1 m^2 quadrats and perform a census of attached benthic organisms to (1) assess coral, sponge, and algae abundance, cover, and health using a consecutive quadrat method and at ELAR, (2) using hand-held, U/W video, develop a coral distribution map for future comparison. If time permits, we will also perform general ecological surveys of the quadrats using hand-held, U/W videography. MTSU grant #2-47401 and PADI Foundation.

37) Clay Harris, Middle Tennessee State University (cdharris@mtsu.edu). FKNMS-2002-003, 1/3/2002 to 12/31/2003. Baseline Assessment of Newfound Harbor Reef System, Big Pine Key, Florida. We propose to perform coral diversity assessments of the 3.8 km long linear reef and patch reefs seaward of the Newfound Harbor Keys, Big Pine Key, and the linear reef of unknown extent seaward of West Summerland Key in the FKNMS. We will investigate coral diversity, abundance, cover, and health using the Atlantic and Gulf Rapid Reef Assessment protocol -- a combined linear transect/random quadrat method -- with more thorough species presence/absence data collected using video transects. Sediment samples will be collected and classified according to grain type and size for comparison with other patch reef sites and existing data for NFHR (Dodd et al., 1973). MTSU grant.

38) Clay Harris, Middle Tennessee State University (cdharris@mtsu.edu). FKNMS-2002-004, 1/3/2001 to 12/31/2002. Decadal-scale Changes in Coral Distribution on a Shoal in Spanish Harbor, Big Pine Key, Florida. We propose to perform a survey of coral and vegetation distribution and abundance on the NW margin of the SHS and at a currently undetermined site farther offshore (SH-HB). For both sites, we will: (1) assess coral, algae, and sea grass diversity, abundance, cover, and health using a consecutive quadrat method covering an area of 112 m^2 and

(2) using hand-held, U/W video, develop a coral distribution map for future comparison. We will later compare our results for SHS to that of Kissling (1965), and assess the changes in coral abundance and distribution after 37 years. MTSU grant.

39) Mark Hay, Georgia Institute of Technology (mark.hay@biology.gatech.edu). FKNMS-2002-071, 7/20/2002 to 12/31/2002. Effects of Algal Secondary Metabolites on Feeding by Herbivorous Fishes and on Spatial Competition with Corals. Our objectives are to (1) determine palatability of common algae to specific species of herbivorous fishes, (2) determine the role of microbial gut symbionts in allowing some species to consume toxic seaweeds, (3) determine which seaweeds are most harmful to corals, and (4) understand how interactions of seaweed defenses, herbivore diversity, and coral-seaweed interactions combine to affect reef structure and function. NOAA National Undersea Research Center, NSF, Teasley Endowment.

40) Michael Heithaus, Mote Marine Laboratory (mheithaus@mote.org). FKNMS-2002-007, 1/24/2002 to 5/31/2002. Acoustic Monitoring of Bull Shark and Great Hammerhead Shark Residency Periods in a Reef Habitat of the Florida Keys. The overall goal of this project is to determine the habitat use and residency periods of great hammerhead (*Sphyrna mokarran*) and bull (*Carcharhinus leucas*) sharks in both the Florida Keys and Charlotte Harbor, FL. This permit application is to deploy four fixed-site monitoring stations near (but outside) the Looe Key Sanctuary Preservation Area to detect the presence of sharks fitted with acoustic transmitters. Every time a shark with a transmitter passes near a station, its identity and time of arrival and departure will be archived. NMFS grant to Mote Marine Center for Shark Research.

41) John Hunt, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute (john.hunt@fwc.state.fl.us). FKNMS-2002-005, 1/7/2002 to 12/31/2004. Spiny Lobster Puerulus Monitoring Program. Influx of postlarval spiny lobsters is monitored using artificial settlement collectors that are placed in the nearshore waters on the Atlantic side of Long Key and Big Munson Key. We will replace the existing cinderblock anchoring systems with permanent, low profile stainless steel mooring eyes cemented into the substrate. FMRI base budget.

42) Claudia Jones, University of Pennsylvania (impglee@aol.com). FKNMS-2002-070, 8/23/2002 to 4/1/2003. The Effect of Climate Change and Rising Nutrient Levels on the Health of Selected Reefs in the Eastern Caribbean. Funding source unknown.

43) Brian Lapointe, Harbor Branch Oceanographic Institution (lapointe@hboi.edu). FKNMS-2001-057, 8/9/2001 to 12/31/2002. A Comparative Study of Water Quality and Coral Reef Status at the Content Keys, Looe Key National Marine Sanctuary, and Biscayne National Park. The objective of this project is to monitor, at monthly frequencies, nutrient concentrations, chlorophyll a, and turbidity at three stations along a spatially large eutrophication gradient. Additional research on remote sensing of algal blooms will be conducted. HBOI.

44) Tom Lee, University of Miami, Rosenstiel School of Marine and Atmospheric Science/MPO (tlee@rsmas.miami.edu). FKNMS-2001-006, 2/23/2001 to 2/28/2003. Florida Keys and Florida Bay Circulation and Exchange Project. This project continues work on current patterns and water circulation in the Florida Keys National Marine Sanctuary and Florida Bay that was initiated in

1989. South Florida Ecosystem Restoration, Prediction, and Modeling program under NOAA/COP (Yeung) and RSMAS/U. Miami (Lee). [Summary of findings in annual report]

45) James Leichter, Scripps Institution of Oceanography (leichter@coast.ucsd.edu). FKNMS-2002-035, 5/13/2002 to 12/31/2003. Responses of Benthic Macroalgae to High Frequency Upwelling on the Florida Keys Reef Tract. The goal of this project is to examine the consequences of high frequency nutrient upwelling for benthic macroalgal populations on and seaward of the Florida Keys reef tract. NOAA/National Undersea Research Center.

46) Niels Lindquist, University of North Carolina at Chapel Hill, Institute of Marine Sciences (nlindquist@unc.edu). FKNMS-2001-010, 3/15/2001 to 12/31/2003. Tracing Marine Sponge Responses to Environmental and Water Quality Gradients and Anti-Predator Defenses Among Marine Hydroids and File Clams. For "Tracing Marine Sponge Responses to Environmental and Water Quality Gradients" we will use natural abundance stable isotope analyses of sponges to provide a unique view of their nutritional ecology, including the contributions of their symbionts to their nutritional needs and to possibly measure the magnitude of symbiont inputs, the effect of water quality on sponge stable isotope values, and the source of bioactive compounds that protect many sponges against predators, competitors and pathogens. For "Anti-Predator Defenses of Marine Hydroids: Alternative Strategies, Biogeographic Patterns, and Ecological Implications", recent studies have demonstrated that hydroids can be defended from predators by two distinctly different mechanisms - stinging nematocysts or distasteful secondary metabolites. Data from our investigations will be used to rigorously test the hypothesis that trade-offs exists among defense systems, particularly in marine organisms. Our studies will also be used to examine the hypothesis that mesofauna abundance and diversity will be lower among nematocyst defended hydroids than among chemically defended hydroids because stinging nematocysts can harm associated mesofauna. For "Evolution of a Chemical Defense Among File Clams (Bivalvia: Limidae) - Relationships Between Bivalve Palatability, Shell Morphology, and Shell Strength", in general, chemically defended organisms lack physically protective structures. We are investigating the robustness of this relationship in using an unlikely group of animals to have a chemical defensive – i.e. bivalve molluscs. The Limidae bivalves are providing an excellent system to test evolutionary relationships among susceptibility to predators and the value of a physical vs. a chemical defense. Furthermore, with the ability to build molecular phylogenies and an excellent fossil record, our data on extant Limidae and other bivalve species may provide a window into ecological and community structure of ancient reef habitats. An additional project, started in September 2002, is a subproject of the above research. Previous studies have shown that small epiphytic algae can alter the palatability of larger macrophyte to various herbivores. Given that marine hydroids are common epibionts on both marine plants and sessile invertebrates, we wish to test that hypothesis that epibiotic hydroids on seaweeds and seagrasses alter their palatability to herbivores. This hypothesis will be tested by offering individual urchins a choice between two pieces of the same seaweed species (mass measured at the beginning of the experiment) one with epibiotic hydroids and one lacking hydroids. The relative rates of herbivory on the two pieces will be statistically compared. This analysis will be run for various combinations of seaweed/seagrass-hydroid combinations. NURC/UNCW #2000-24, NSF (#0002723 and 0082049), and by UNC funding.

47) Diego Lirman, University of Miami, Rosenstiel School of Marine and Atmospheric Science (dlirman@rsmas.miami.edu). FKNMS-2001-027, 6/13/2001 to 12/31/2002. Coral Size-Frequency Distributions as Indicators of Reef Health: Monitoring and Modeling Approaches. We propose to implement a demographic approach to assess the condition of coral populations within patch reefs of the FKNMS that will incorporate individual-based parameters such as growth, survivorship, partial mortality, and fragmentation. These measures can reveal sublethal differences among populations that abundance and diversity measures alone may miss. NURC project #UNCW2001-07.

48) Carrie MacKichan, Georgia Southern University (carrie_a_mackichan@gasou.edu). FKNMS-2002-010, 4/1/2002 to 12/31/2002. Effects of Ultraviolet Radiation on Newly Settled Coral Recruits. This project will investigate the effects of ultraviolet radiation on newly settled coral recruits and determine their ability to protect themselves from damage by this radiation. Information garnered from this study will help explain patterns of distribution and abundance observed in shallow water coral reef communities. Internship at Mote Marine Laboratory Center for Tropical Research, Georgia Southern University Academic Excellence Grant, faculty advisor support at GSU, and other sources of funding where applied for.

49) Kevin Madley, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute (kevin.madley@fwc.state.fl.us). FKNMS-2001-020, 4/16/2001 to 4/15/2003. Florida Inshore Marine Monitoring and Assessment Program (IMAP). The goal of this project is to create a statewide assessment of the environmental quality of inshore habitats by collecting information on various environmental indicators. The project is part of a long-term environmental monitoring program of over two dozen chemical, physical, and biological indicators under the U.S. EPA Coastal 2000 initiative. U.S. EPA Assistance Agreement #CR 827240-01-0.

50) Mikhail Matz, University of Florida (matz@whitney.ufl.edu). FKNMS-2002-039, 5/31/2002 to 6/1/2003. Genetics, Ecology and Evolution of Coloration in Great Star Coral, *Montastraea cavernosa*. In reef-building corals each visually perceptible basic color is essentially determined by the sequence of a single protein, homologous to green fluorescent protein (GFP) from jellyfish *Aequorea victoria*. This provides a unique opportunity to address the question of color evolution in the environment directly by applying the tools of molecular phylogenetics designed for sequence analysis and, in addition, to characterize and monitor variations in coloration in terms of expression of individual genes. The ultimate goal of the project is to understand the evolutionary mechanisms and ecological factors that determine the diversity of coloration in reef-building corals. UF/Whitney Laboratory.

51) Paula Mikkelsen, American Museum of Natural History (mikkel@amnh.org). FKNMS-2000-036, 6/30/2000 to 6/30/2002. Qualitative Survey of Ocean-side Infaunal Molluscan Diversity off the Florida Keys. This multi-phase project will produce the first baseline survey of mollusks associated with coral reef habitats in the Florida Keys. The work proposed here will fill a critical gap in this survey by facilitating equivalent coverage of the coral reef environments now managed by the Florida Keys National Marine Sanctuary. This proposal seeks to resample several deepwater sites as part of the rigorous sampling program of infaunal molluscan communities of the Florida Keys. Private institution funding.

52) Paula Mikkelsen, American Museum of Natural History (mikkel@amnh.org). FKNMS-2002-079, 7/15/2002 to 8/31/2002. International Marine Bivalve Workshop. A 2-wk workshop on marine bivalves with an emphasis on systematics, anatomy, and natural history, will be held to further the scientific knowledge of living marine bivalves of the Florida Keys and to train students in this understudied field of modern malacology. Twelve invited expert scientists from an international set of renowned academic institutions will work one-on-one in research teams with a similarly diverse group of 12 graduate students, supported by an organizing and support team. A series of refereed, publishable manuscripts on selected bivalve species or groups, one from each of the scientist-student teams, will be published in a dedicated issue of a peer-reviewed academic journal. National Science Foundation, Partnerships in Enhancing Expertise in Taxonomy [PEET] Program, award #9978119. Additional support is provided by the Bertha Lebus Charitable Trust, Comer Science & Education Foundation, The Field Museum, and the American Museum of Natural History.

53) Margaret Miller, National Marine Fisheries Service, Southeast Fisheries Science Center (margaret.w.miller@noaa.gov). FKNMS-2000-050, 7/1/2000 to 12/31/2002. Evaluation of FKNMS Reef Restoration Structures: Elements that Foster Coral Recruitment Success. This project aims to test hypotheses derived from observations of in-situ coral recruitment on the restoration structures at the Elpis and Maitland grounding sites. This study should determine what aspects of structure design account for the observed differences in coral recruitment success, hence providing sound basis for future structure design. NOAA/MSD (Lisa Symons).

54) Margaret Miller, National Marine Fisheries Service, Southeast Fisheries Science Center (margaret.w.miller@noaa.gov). FKNMS-2000-052, 8/14/2000 to 6/30/2002. Restoration of Coral Reef Fisheries Habitat by Enhancement of Coral Recruitment via Improved Substrate Quality, Larval Seeding, and Sea Urchin Re-introduction. This project aims to develop effective ecological restoration techniques for degraded coral reefs via culturing and re-seeding key hermatypic coral species and keystone grazing urchins. National Sea Grant Fisheries Habitat Program (via North Carolina Sea Grant) award.

55) Steven Miller, NOAA National Undersea Research Center/University of North Carolina at Wilmington (smiller@gate.net). FKNMS-2001-080, 11/6/2001 to 6/30/2002. Fish Tracking, Coral Bleaching, and Coral Growth Studies in the Florida Keys National Marine Sanctuary (Development Projects). Fish will be tagged and tracked from topside and from inside Aquarius using two acoustic telemetry systems and an external tagging program. Three hydrophones will be deployed for 6 months within the Conch Reef Research-Only Area and two hydrophones will be deployed approximately one mile outside the Conch Reef ROA toward Pickles Reef and Davis Reef. Coral studies will also be conducted to evaluate how increasing amounts of carbon dioxide in the atmosphere might affect seawater chemistry and coral calcification. NURC/UNCW.

56) Lisa Monk, Center for Marine Conservation (now The Ocean Conservancy) (Lmonk@vacmc.org). FKNMS-2001-003, 2/7/2001 to 2/6/2002 and FKNMS-2002-022, 4/19/2002 to 12/31/2003. RECON (Reef Ecosystem Condition) Program. RECON is a low-tech, rapid monitoring protocol for volunteer divers. RECON divers are trained by CMC-certified

RECON instructors to collect information on the condition of coral reef ecosystems. The goals of RECON are to broaden the scope of available information about the benthic organisms on coral reefs, to alert local reef researchers and managers of changing reef conditions (e.g., mass bleaching events, outbreaks of disease, nuisance algal blooms, changes in abundance of key mobile invertebrates), and to increase public understanding of the threats to coral reef ecosystems. U.S. EPA grant.

57) Leonid Moroz, University of Florida (moroz@whitney.ufl.edu). FKNMS-2001-058, 9/10/2001 to 12/31/2003. Coral Screening Project. This project is designed to screen a wide sampling of corals to accomplish two goals from one collection. First, we want to see if any local corals contain yellow or red fluorescing proteins. Second, we want to search for the presence of the enzyme nitric oxide synthase, which generates the gaseous messenger molecule nitric oxide. University of Florida.

58) Alison Moulding, University of Miami, Rosenstiel School of Marine and Atmospheric Science (amouldin@rsmas.miami.edu). FKNMS-2002-014, 4/1/2002 to 3/31/2003. Coral Recruitment in the Florida Keys and the Relationship Among Adult Abundance, Larval Supply, and Recruitment of *Porites astreoides*. The objectives of this study are to examine coral recruitment along the Florida reef tract and to explore the relationship among presence of adult colonies, fertilization success, and recruitment of juveniles of one species of coral common in the Florida Keys: *Porites astreoides*, a hermaphroditic, brooding coral. By including Florida Keys reefs in this study, a better understanding of the mechanisms of supply and recruitment can be obtained. RSMAS and RSMAS Founders Research Fund award.

59) Erich Mueller, Mote Marine Laboratory (emueller@mote.org). FKNMS-2002-013, 3/1/2002 to 2/28/2003 and FKNMS-2003-005, 3/1/2003 to 2/29/2004. Effect of Mosquito Control Pesticides on *Porites astreoides* Planula Larvae. This study aims to determine how mosquito adulticides affect the survival and viability of planula larvae from the scleractinian coral, *Porites astreoides*. Larval responses will be assessed following exposure to the mosquito adulticides, Naled and Permethrin, individually and combined, to simulate synergistic responses. Larvae will be dosed over a lethal and sublethal concentration range and a variety of endpoints recorded. Mote Marine Laboratory Research Fellowship.

60) Ken Nedimyer, Sea Life, Inc. (sealife@terranova.net). FKNMS-2001-069, 9/1/2001 to 12/31/2002. Techniques Development for the Reestablishment of Populations of the Long-Spined Sea Urchin, *Diadema antillarum*, on Two Small Patch Reefs in the Upper Florida Keys. The overarching goal of this project is to monitor and track the success of one technique to enhance and restore coral reef areas. Specifically, the transplantation of large numbers of small *Diadema antillarum* from shallow rubble zones to deeper patch reefs will be evaluated. Additionally, the resulting effects of increased densities of *Diadema antillarum* to approximate pre-plague levels on small, isolated patch reefs will be monitored to determine if a reduction of algal overgrowth will enhance coral growth and settlement. Funded by NMSP.

61) David Palandro, University of South Florida, Institute for Marine Remote Sensing (palandro@seas.marine.usf.edu). FKNMS-2002-067, 7/28/2002 to 8/10/2002. A Multi-Scale and Multi-Sensor Approach to Monitoring the Florida Keys National Marine Sanctuary. This study

aims to form a time series of satellite remote sensing images over the past 18 years to map and monitor coral reef ecosystem change. By ground-truthing current reef conditions and benthic coverage it is possible to calibrate archived satellite data to obtain benthic coverage in the past, which will allow us to complete a change detection study. NASA Fellowship (NGT5-30414).

62) Mark Patterson, Virginia Institute of Marine Science (mrp@vims.edu). FKNMS-2002-088, 11/4/2002 to 11/22/2002. Flow Modulated Metabolism: Connection with Coral Bleaching and Reef Oxygen Crises? Our previous NURP and NSF sponsored work demonstrated the importance of flow-modulated metabolism in lower invertebrates, in particular reef corals, at the level of the individual organism (colony). We propose to examine HSP expression within a colony during the (asymmetric) bleaching process. The measurement of reef scale oxygen dynamics using an AUV provides an opportunity to connect what occurs at a microscale around individual corals, to the macroscale. NOAA/National Undersea Research Center, Key Largo.

63) Joseph Pawlik, The University of North Carolina at Wilmington (pawlikj@uncwil.edu). FKNMS-2001-021, 4/16/2001 to 12/31/2002. Investigations of Chemical and Physical Defenses of Reef and Mangrove Demosponges. This research program represents a continuation of the first systematic investigation of the chemical defenses of Caribbean marine sponges. Recruitment processes, natural and human-caused changes to coral reefs, biodiversity and ecosystem structure and function, and new products from the sea will be the focus projects of this research. National Undersea Research Center/UNCW.

64) Gregory Piniak, NOAA/NOS, Center for Coastal Fisheries and Habitat Research (gregory.piniak@noaa.gov). FKNMS-2002-087, 9/1/2002 to 2/28/2003. Fluorescence as a Tool for Enumerating Coral Recruits. Fluorescence technology is useful in locating coral recruits and other small reef organisms that are difficult to detect with the naked eye. We propose a study to determine the capability of fluorescent technologies to identify and enumerate coral recruits, and to rigorously compare these techniques with current methods used to quantify coral recruitment on natural and artificial substrates. NOS.

65) Patrick Pitts, U.S. Fish and Wildlife Service (patrick_pitts@fws.gov). FKNMS-2002-036, 5/13/2002 to 5/12/2003. Florida Keys Tidal Restoration. The Florida Keys Tidal Restoration Project, a component of the Comprehensive Everglades Restoration Plan, is designed to restore tidal circulation in the middle Florida Keys in order to improve water quality and the health and composition of flora and fauna in the project area. The U.S. Fish and Wildlife Service (USFWS) will to provide guidance to the U.S. Army Corps of Engineers, the agency in charge of project construction, regarding ecological and environmental concerns, including threatened and endangered species. In order to provide this guidance, the USFWS will need to conduct field surveys to determine fish and wildlife resources in the project area. Fish and Wildlife Coordination Act transfer funding from the U.S. Army Corps of Engineers.

66) Susan Richardson, Smithsonian Marine Station at Fort Pierce (richardson@sms.si.edu). FKNMS-2002-008, 2/11/2002 to 12/31/2003. Diversity, Distribution, and Abundance of Foraminiferans in Seagrass Habitats, Florida Keys. Benthic foraminiferans, both epiphytic and sediment dwelling, will be sampled from seagrass habitats in the Florida Keys. The diversity, distribution, and abundance of foraminiferal faunas will be characterized and compared and

contrasted to similar sites in the Indian River Lagoon and Belize. Smithsonian Institution Postdoctoral Fellowship.

67) Laurie Richardson, Florida International University (richardl@fiu.edu). FKNMS-2001-075, 10/17/2001 to 12/31/2002. Distribution and Etiology of Two Coral Diseases in the Florida Keys National Marine Sanctuary: Black Band Disease and White Plague Type II. This research constitutes continuation of our work on coral diseases in the FKNMS, and specifically addresses several hypotheses that have grown out of our work and which directly address both overall and specific objectives outlined in the WQPP. Unknown, previously funded by EPA WQPP Special Studies.

68) Eugene Shinn, U.S. Geological Survey, Center for Coastal Geology (eshinn@usgs.gov). FKNMS-2002-080, 8/5/2002 to 10/1/2002. Health, Growth History, and Microbial Content of Large Head Corals at Looe Key. The purpose of this research is to reoccupy and sample large coral heads sampled during NOAA-funded research in 1982 and 1987. The heads will be core drilled by Harold Hudson of NOAA using a smaller diameter core barrel rather than the 4-inch barrel originally used. All holes will be plugged with cement to allow overgrowth of the sample sites. USGS.

69) Shauna Slingsby, University of North Carolina at Wilmington (sns3162@uncwil.edu). FKNMS-2001-037, 7/5/2001 to 12/31/2002. Nutrient Cycling and Accumulation Differences between SPA and non-SPA Sites and Nutrient Enrichment and its Effect on Coral/Algal Interactions. This project will test the following hypotheses: 1) Topographic complexity contributes to higher abundances of coral, algae, and herbivorous fish which effects a reef's internal nutrient cycling and processes of nutrient accumulation. 2) Due to increased nutrient input, certain species of macroalgae, like *Dictyota* spp., quickly colonize dead skeletal areas of stony coral colonies, causing recession of live coral tissue. National Center for Caribbean Reef Research (NCORE) - UNCW and RSMAS/U. Miami.

70) Ned Smith, Harbor Branch Oceanographic Institution (nsmith@hboi.edu). FKNMS-2002-063, 9/16/2002 to 9/30/2003. Nutrient Mass Fluxes between Florida Bay and the Florida Keys National Marine Sanctuary through Florida Keys Passes. Current speed/direction and water level will be measured to estimate volume transport through Long Key Channel and Moser Channel. Volume transports will be combined with nutrient concentrations to calculate nutrient transport. Measurements made during a one-year field study will quantify the magnitude and direction of seasonal and long-term net nutrient transport between Florida Bay and Hawk Channel. NOAA/Coastal Ocean Program.

71) Colette St. Mary, University of Florida (stmary@zoo.ufl.edu). FKNMS-2001-019, 5/1/2001 to 5/1/2003. The Effects of Artificial Reef Habitats on Fish Production. The goal of this project is to quantify the net effect of new habitat on fish production, enhance the sustainability of the marine ornamental fishery, and directly test the attraction-production hypotheses. To successfully conduct the critical field experiment, we need to optimize its design, which will depend upon patterns of spatial and temporal variance in settlement and abundance, the strength of density-dependence and the degree of movement between the artificial and natural reefs (as well as diffusion among the natural reef habitat). We will accomplish this by integrating field

studies, quantitative literature syntheses, and mathematical population dynamic models. National SeaGrant Program.

72) Gregg Stanton, Florida State University (gstanton@res.fsu.edu). FKNMS-2000-044, 7/28/2000 to 12/31/2002. Investigation of Skin Lesions in Gray Snapper (Neurofibromatosis). This study evaluates gray snapper, bicolor damselfish, and other affected snappers with observable signs of neurofibromatosis and also black spots that are potentially associated with a parasite cyst. This project will address public concern over large numbers of diseased fish, investigate disease processes and potentially provide information that will conserve resources. FSU.

73) Peter Swart, University of Miami, RSMAS (pswart@rsmas.miami.edu). FKNMS-2000-018, 4/3/2000 to 12/31/2003. The Origin and Recycling of Nutrients and an Investigation of Trophic Dynamics. The research proposed here is designed to generate an integrated data set, combining work on the sources of nutrients (Swart), cycling and fates of nitrogen and carbon (Swart and Szmant), nutrient flux and interactions with currents (Lee), the production of organic material by algae (Szmant) and energy flow between trophic levels (Cowen and Sponaugle). National Center of Caribbean Coral Reef Research.

74) Alina Szmant, University of North Carolina at Wilmington (szmanta@uncwil.edu). FKNMS-2002-054, 6/17/2002 to 6/30/2003. Research on Nutrient Dynamics, Algal Community Structure, and Algal Productivity. Regional coral reef decline is indicated by rapid loss of coral cover and increases in algal cover. It is important to be able to distinguish between increased algal cover being a symptom of coral decline (e.g. algal colonizing substrate vacated by coral killed by one factor or another) vs. a causative factor (algae over-growing and killing the coral), especially if the latter is the result of anthropogenic nutrient enrichment of reef areas. Thus, a major objective of this NCORE subcontract will be to address factors that affect relative algal dominance. These include nutrient availability and cycling, and grazing pressure. National Center for Caribbean Coral Reef Research at the Univ. of Miami, funded by U.S. EPA. Subcontract to UNCW.

75) Florence Thomas, University of South Florida (fthomas@chuma1.cas.usf.edu). FKNMS-2002-041, 6/1/2002 to 12/31/2003. The Effects of Water Velocity/Hydrodynamics on Mass Transfer of Nutrients: a Partnership in Research and Education. This project explores the relationship between water velocity, nutrient uptake, and the morphology of the predominant community members of nearshore benthic communities, including seagrasses (i.e. *Thalassia testudinum*, *Halodule wrightii*) and macroalgae (i.e. *Halimeda* sp.). As the title implies, this NSF-funded project links research in hydrodynamics and biomechanics to public, k-12, undergraduate, and graduate education. Minority participation is encouraged at all levels and is the primary focus of recruitment at the undergraduate level. Supported by a 5-year NSF PECASE award to Dr. Thomas (OCE-9701434).

76) John Valentine, Dauphin Island Sea Lab (jvalentine@disl.org). FKNMS-2002-026, 4/29/2002 to 12/31/2002. Trophic Cascades and Spatial Subsidies in a Coral Reef Ecosystem: A Field Test using ‘No-Take’ Areas in the Florida Keys National Marine Sanctuary. We propose to take advantage of newly created “no-take” protected areas in the Florida Keys to better understand the role of large predatory fishes in controlling the flow of energy between habitats in

subtropical and tropical marine ecosystems. Most fundamentally, we hypothesize that the successful restoration of reef food webs will depend on the size and location of nearby seagrass habitats, which provide both nursery and a foraging ground for reef fishes. We predict that there will be substantial differences in the community structure of fishes and invertebrates not only within the reefs of the FKNMS marine reserves but also in adjacent seagrass habitats. Furthermore, we propose to use the findings from this study to make data-based predictions as to the minimum requirements for the development of effective marine reserves in areas such as the Florida Keys. Andrew Mellon Foundation Ecosystem Research Program 2001-2003. MARFIN grant 2002-2004.

77) John Valentine, Dauphin Island Sea Lab (jvalentine@disl.org). FKNMS-2002-027, 4/29/2002 to 12/31/2002. FKNMS-2002-027, 4/29/2002 to 12/31/2002. The Trade-offs of Living in Mangrove Forests: Finding a Balance between Energetic Needs and Protection. This project will investigate the importance of habitat linkages, between mangroves and seagrass beds, in controlling the density and diversity mangrove-associated consumers. To do this we will conduct a series of manipulative field experiments, collect samples of prey and document the composition of consumers along the intersection between mangroves and seagrass beds in the lower Florida Keys. We anticipate that our data will show that while mangroves provide shelter from predators for smaller fishes, these consumers forage into the adjacent seagrass beds to meet their energetic requirements. Put simply the presence of two habitats will allow higher densities of these consumers to exist then would otherwise be possible if they were forced to hide and feed in a single habitat. From this study, we anticipate that we will be able to provide new evidence that there is a need to focus management activities on the importance of habitat diversity as a tool for managing the nation's coastal food webs. Andrew Mellon Foundation Ecosystem Research Program 2001-2003. MARFIN grant 2002-2004.

78) Douglas Weaver, United States Geological Survey, Florida Caribbean Science Center (doug_weaver@usgs.gov). FKNMS-2001-050, 8/1/2001 to 8/31/2002. Inventory of Deepwater Reef Fishes and Habitat Mapping of Tortugas South Ecological Reserve. This project will assess the relative abundance of large predatory fishes (piscivores and other large carnivores) and identify the relative trophic structure and abundance of the reef fish assemblage (primarily planktivorous fishes) along deep-water areas (50 to ~300m) of Tortugas South Ecological Reserve (TSER). Funds from the National Fish and Wildlife Foundation, Grouper Spawning Aggregation Study #2000-0243 through the University of Florida Department of Fisheries and Aquatic Sciences.

79) Gerard Wellington, University of Houston (wellington@uh.edu). FKNMS-2002-081, 7/31/2002 to 8/31/2003. Genetic Variation and Phenotypic Response of *Montastraea faveolata*. The first, experimental project will estimate the heritability of metabolic and molecular characters related to stress response of *M. faveolata*. To date, heritability of both metabolic and molecular characters related to stress have not been investigated in any coral species. The purpose of the study will be to investigate the contribution of genetic vs. non-genetic (environmental and symbiont association) effects associated with *M. faveolata* response to stress. The second project will be exploratory in nature. Currently, the genetic population structure for *M. faveolata* has not been investigated. The purpose of my project will be to collect preliminary

data to test for significant genetic variation along the Florida Keys for *M. faveolata*. Houston Coastal Center.

80) David Wethey, University of South Carolina (wethey@biol.sc.edu). FKNMS-2002-089, 10/1/2002 to 12/31/2002. Decoupling the Effects of Mass Transfer, Water Motion, and Temperature on Reef Health. This project has the interrelated objectives of 1) measuring the effects of flow speed on oxygen transfer by common species of coral of flat, mound-shaped and branching morphology; 2) experimentally determining the effects of O_2 accumulation on corals in field conditions; 3) quantifying the interaction between temperature and flow on photosynthesis under natural field conditions. NOAA/National Undersea Research Center.

81) Jennifer Wheaton, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute (jennifer.wheaton@FWC.state.fl.us). FKNMS-2001-015, 4/16/2001 to 12/31/2003. Coral/Hardbottom Monitoring Project. The coral/hardbottom monitoring project documents status and trends (change) in stony coral species presence and percent cover of selected attached reef benthos. Documentation of degree of bioerosion will be a subset of the project beginning summer 2001. Established in 1995, the project's 43 sampling sites, which include 7 hardbottom, 11 patch, 12 offshore shallow, and 13 offshore deep reef sites are sampled annually. The project's primary goal is to document change in the presence/absence of stony coral species richness and selected disease categories and relative percent cover of corals, octocorals, sponges, macroalgae, and substrate. U.S. EPA, FKNMS. [Summary of findings in annual report]

82) Jennifer Wheaton, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute (jennifer.wheaton@FWC.state.fl.us). FKNMS-2001-016, 4/16/2001 to 4/30/2002. Nitrogen Stable Isotope Records in *Plexaura homomalla* from the Florida Keys. Samples of the axis of a common FKNMS gorgonian (*Plexaura homomalla*) will be analyzed to document the nitrogen stable isotope record in the organic fraction of the skeleton as a measure of surface productivity. Collections conducted under U.S. EPA, FKNMS funding for the CRMP. Analyses and writing funding provided by Dr. Michael Risk, McMaster Univ.

83) Cheryl Woodley, NOAA National Ocean Service, National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Environmental Health & Biomolecular Research (cheryl.woodley@noaa.gov). FKNMS-2001-008, 4/1/2001 to 4/30/2003. Assessment of Coral Health in the FKNMS Using a Molecular Biomarker System (MBS). We have developed a Molecular Biomarker System (MBS) capable of determining whether corals are stressed and causative agents associated with that stress. The MBS works because the biomarkers respond to stress along biochemical and cellular pathways common to all organisms, from bacteria and protists to plants and higher animals. National Sea Grant Consortium collaborators include NOAA/NOS/NCCOS, Med. Univ. of South Carolina, FKNMS, Biscayne National Park, Univ. of South Florida, Univ. of Charleston, Coral Shores High School, and EnVirion Biotechnologies, Inc. These specific proposed projects are a subset of larger proposed projects to National Sea Grant and U.S. EPA and form a collaboration between the National Marine Sanctuary Program and NCCOS. [Summary of findings in annual report]

Research Permits Issued by the Florida Keys National Marine Sanctuary: 2003

Information included below: Name of principal investigator and contact information, permit number and duration, project title, project summary, and funding source (if provided).

1) Andrew Baker, Wildlife Conservation Society and Columbia University (abaker@wcs.org). FKNMS-2002-073, 9/23/2002 to 8/31/2003. Symbiont Distributions in Reef Corals as Indicators of Recent Environmental History. This research uses molecular techniques to identify the dinoflagellate symbionts (*Symbiodinium* spp.) of reef-building corals from the Florida Keys reef tract (and the National Marine Sanctuary in particular). It tests for differences in the distribution of symbionts that correlate with environment, and tests the stability of these distributions by transplanting coral colonies between different environments, with and without exposure to a bleaching stimulus. National Undersea Research Program, UNCW.

2) Rodney Bertelsen, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute (rod.bertelsen@myfwc.com). FKNMS-2003-069, 11/1/2003 to 10/31/2004. Spillover of Lobsters from the Western Sambo Ecological Reserve and Evaluation of Exchange of Exploited Species Between a Marine Protected Area and an Adjacent Potentially Attractive Unprotected Habitat. There are two projects being undertaken in this research. In the first, we propose to study lobster movement patterns around the patch reef environment in the Western Sambo Ecological Reserve (WSER) using a two-tiered design, tagging lobsters with both traditional antenna tags and sonic tags. Antenna tags will be use to determine abundance and net lobster movement after a one month time interval. Sonic tags will be used to determine fine-scale, inter-patch reef movements on a minute-by-minute basis over the course of a month. We will also use a detailed GIS-based habitat map of the area to determine how benthic habitats may influence lobster movement patterns. In the second study, we propose to monitor and evaluate reproductive migrations and other exchanges of lobsters and fish between the WSER and the adjacent offshore bar by using a combination of diver-based population surveys and monitoring of the movements of tagged individuals using both conventional tags and active and passive ultrasonic telemetry, supplemented by diver and ROV direct observations of the movements and behaviors of tagged individuals. Prior to the initial work with the animals, a habitat map of the study area will be created using a GPS based towable underwater color camera system. Project 1 is funded by the U.S. Environmental Protection Agency. Funding for project 2 is pending from NOAA/National Undersea Research Center, Key Largo.

3) Carole Bewley, National Institutes of Health (cb194k@nih.gov). FKNMS-2002-069, 10/14/2002 to 12/31/2004. Investigations of Carbohydrate-Binding Proteins from Marine Cyanobacteria. Collect cyanobacteria samples from subtropical waters and investigate the presence of carbohydrate binding proteins. If such proteins are present, we will determine their optimal ligands and the source of their natural receptors using biochemical and chemical techniques. National Institutes of Health.

4) Jill Borger, University of Miami, Rosenstiel School for Marine and Atmospheric Sciences (jborger@rsmas.miami.edu). FKNMS-2002-064, 11/27/2002 to 12/31/2003. Coral Disease Ecology and the Effects of Disease on Reproduction. This project is an extension of work begun

last year. The permit will cover two projects; the first involves a detailed examination of specific reef sites in order to follow the specific incidence, movement and transmission of coral diseases over time. This will involve non-destructive sampling methods, such as transect lines and quadrats, and detailed maps of each site will be constructed. The second project will examine the effects of disease on coral reproduction. A few samples will be taken from both diseased and healthy colonies and total fecundity, or reproductive output, will be measured histologically. The fecundity values for diseased and healthy colonies will be compared and analyzed. Reitmeister Award and anonymous donation to Jill Borger.

5) Joan Browder, NOAA/National Marine Fisheries Service (joan.browder@noaa.gov). FKNMS-2002-002, 1/3/2002 to 12/31/2003. Post-larval Sampling Project. The purpose of the sampling project is to describe spatial and temporal patterns of postlarval pink shrimp immigration to potential nursery grounds in Florida Bay from offshore spawning grounds. Accessibility of potential nursery grounds to pink shrimp postlarvae (i.e., postlarval ingress rate) may be an important factor limiting the Bay's capacity to produce pink shrimp recruits to the Tortugas fishing grounds. NOAA/NMFS Southeast Fisheries Science Center.

6) Michael Burton, NOAA/National Marine Fisheries Service (michael.burton@noaa.gov). FKNMS-2002-034, 5/8/2002 to 3/31/2003. Biological Characterization of Riley's Hump and Identification of Spawning Areas. Visual census transects (SCUBA) will be used to quantify mutton snapper abundance in the vicinity of Riley's Hump and compare it to baseline data. Habitat will be characterized by divers using 0.5 m^2 quadrats. NOAA/NMFS Coral Reef Initiative.

7) Mark Butler, Old Dominion University (mbutler@odu.edu). FKNMS-2002-043, 6/5/2002 to 6/4/2003. Characterization of Hardbottom Community Dynamics: Sponges, Octocorals, Lobsters, & Octopus. My research team is currently working on several related projects involving the shallow, hard-bottom communities so common throughout the Florida Keys. In some cases, our research is focused on the ecology of single species of specific ecological or economic importance (e.g., spiny lobster, commercial sponges, and octopus). In other cases, our research involves community-level assessment and the influence of environmental (e.g., salinity change) or human factors (e.g., fishing) on the structure of hard-bottom communities over large spatial scales. In both cases, we use a combination of field sampling, field and laboratory experimentation, and computer simulation modeling to test hypotheses of interest. National Science Foundation, OCE-0136894 and NOAA Coastal Ocean Program.

8) Roy Caldwell, University of California, Berkeley (4roy@socrates.berkeley.edu). FKNMS-2002-062, 10/18/2002 to 12/31/2003. The Biology of Stomatopod Crustaceans. This proposal focuses on stomatopod crustaceans, asking basic biological questions about their distribution and abundance, reproductive behavior, larval dispersal, and how they communicate in a colorful underwater world. NOAA/National Undersea Research Center, Key Largo.

9) Mary Alice Coffroth, State University of New York at Buffalo (coffroth@buffalo.edu). FKNMS-2002-011, 3/4/2002 to 6/30/2004. A Study of Population Dynamics of Scleractinians on Conch Reef: A Demographic and Population Genetics Approach. In this study the influence of recruitment in establishing species composition of reefs will be examined using a combined

demographic and population genetic approach to record the species composition at two sites on Conch Reef in the Florida Keys. NOAA/National Undersea Research Center.

10) Felicia Coleman, Florida State University (coleman@bio.fsu.edu). FKNMS-2001-005, 2/23/2001 to 2/28/2003. Studies in the Ecology of Red Grouper, *Epinephelus morio*, including their Contribution to Habitat Heterogeneity and Community Structure. The aim of this project is to examine the structure and function of the community of organisms that take up residence in holes occupied by red grouper. These holes, for the most part, appear to be excavated and maintained by red grouper. The resultant communities are rich in sessile invertebrates and various species of cleaning fish. Marine Conservation Biology Institute, SeaGrant, and Environmental Defense.

11) Carrollyn Cox, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute (carrollyn.cox@myfwc.com). FKNMS-2001-022, 4/23/2001 to 12/31/2002. Spiny Lobster Spawning Potential and Population Assessment: A Monitoring Program for the South Florida Fishing Region. The proposed study is part of the Sanctuary's Marine Zone Monitoring Program and seeks to investigate the effects of no-take management on this important fishery resource. FWRI. [Summary of findings in annual report]

12) Alan Duckworth, Harbor Branch Oceanographic Institution (aduckworth@hboi.edu). FKNMS-2001-049, 7/23/2001 to 9/30/2003 and FKNMS-2003-066, 10/1/2003 to 9/30/2004. Aquaculture of the Sponge *Forcepia* sp. for the Sustainable Supply of Bioactive Metabolites for Biomedical Research. The sponge *Forcepia* sp. will be farmed at a depth of 20-25 m near Tennessee Reef to determine if in situ aquaculture can supply sufficient and sustainable quantities of metabolites called lasonolides for biomedical research. The farmed sponges will be harvested at different rates to examine whether regular tissue harvesting can increase overall yield of lasonolides. Sponges will be farmed in mesh arrays, which will be either pegged flat to the substrate or held upright in the water column. One array will be maintained for a longer period and will be used as a supply for ongoing, grant-funded research on the lasonolides. HBOI.

13) Peter Edmunds, California State University at Northridge (peter.edmunds@csun.edu). FKNMS-2002-021, 6/1/2002 to 12/31/2003. Global Climate Change and Coral Recruitment: The Interactive Effects of Temperature and Ontogeny on the Biology of *Porites astreoides* Larvae. The goal of this project is to carry out a multidisciplinary analysis of the biology, physiology and genetics of coral larvae in order to understand how global climate change will affect the coral population structure of reefs such as those in the Florida Keys. NOAA/National Undersea Research Center.

14) David Eggleston, North Carolina State University (eggleston@ncsu.edu). FKNMS-2002-061, 7/2/2002 to 12/31/2003. Fish and Caribbean Spiny Lobster Distribution and Abundance in the Great White Heron National Wildlife Refuge: An Initial Assessment and Comparison with the Key West National Wildlife Refuge. We will use aerial photographs, ground-truthing and GIS computer software to identify and map habitats within the GWHNWR within which to quantify fish and Caribbean spiny lobster. We will use visual surveys conducted by SCUBA divers to quantify fish and lobster, as well as measure specific habitat characteristics. The study

will provide baseline data and be used to make research and management recommendations. Grant from The Ocean Conservancy and U.S. Fish and Wildlife Service.

15) Bill Fitt, University of Georgia, Institute of Ecology (fitt@sparrow.ecology.uga.edu). FKNMS-2001-063, 8/27/2001 to /1/2003. Potential for *Acropora cervicornis* (staghorn coral) and *Acropora palmata* (elkhorn coral) in Coral Reef Restoration: Genetics, Physiology, and Growth. This proposal addresses two major issues concerning populations of *A. cervicornis* and *A. palmata* in the Caribbean: the genetic structure and diversity, and some basic questions concerning transplantation. We will compare populations of both species from two locations: relatively pristine reefs (low human impact) near the Caribbean Marine Research Center on Lee Stocking Island in the Bahamas vs. relatively high human impact sites in the Florida Keys National Marine Sanctuary. NOAA/National Undersea Research Center.

16) Bill Fitt, University of Georgia (fitt@sparrow.ecology.uga.edu). FKNMS-2003-004, 2/18/2003 to 12/31/2004. Long Term Monitoring of Tissue Biomass from Five Species of Reef Corals. This project is a continuation of a seasonal monitoring program designed to document the relative physiological health of coral tissue and zooxanthellae for five major coral species in the Keys. Tissue biomass, levels of proteins, carbohydrates and lipids, C:H:N analysis and zooxanthellae photosynthetic potential, densities and chlorophyll content will be determined every 3 months for five species of corals living on the Florida Reef Tract. NOAA/NURP funding for tissue biomass research. NSF funding (5 years) for Adaptive Bleaching Hypothesis research.

17) Mark Fonseca, NOAA/Center for Coastal Fisheries and Habitat Research (CCFHR) (mark.fonseca@noaa.gov). FKNMS-2001-023, 5/1/2001 to 6/30/2003. Effects of Crab/Lobster Traps to Seagrass Beds of the Florida Keys National Marine Sanctuary (FKNMS): Damage Assessment and Evaluation of Long-Term Recovery. This project will assess the effect (if any) of stationary fishing gear (i.e. crab/lobster traps) to seagrass beds of the FKNMS. Replicate traps will be randomly placed within randomly selected seagrass beds of varying species composition. Intermittent removal of traps will determine the time it takes to sustain injury to the beds. Injury recovery will be tracked quarterly to semi-annually over the following two years. NOS and NMFS.

18) Mark Fonseca, NOAA/Center for Coastal Fisheries and Habitat Research (CCFHR) (mark.fonseca@noaa.gov). FKNMS-2001-029, 6/11/2001 to 6/30/2003. A Novel Technique for the Restoration of Seagrass Propeller Scars: Does Deployment of Sediment-filled, Biodegradable Fabric Tubes in Propeller Scars Enhance Seagrass Regrowth into These Injured Areas? This project will assess the effectiveness of a new method for propeller scar restoration in the FKNMS. Fabric tubes and bird stakes will be deployed into existing propeller scars in a replicated experiment. Intermittent monitoring of treatments will be tracked quarterly to semi-annually over the following two years. NOS.

19) Mark Fonseca, NOAA/Center for Coastal Fisheries and Habitat Research (CCFHR) (mark.fonseca@noaa.gov). FKNMS-2002-009, 2/15/2002 to 12/31/2003. Characterization and Analysis of Seagrass Injury and Recovery on Shallow Seagrass-Coral Banks in the FKNMS. The objectives of this study are to develop a comprehensive database of the complete range of injury categories and the widest possible range of injury ages and species combinations to be modeled

in the Habitat Equivalency Analysis. In addition to these detailed injury sites, we will characterize the current conditions on the entire Red Bay bank system using 1/9600 scale vertical aerial photography integrated with differential global positioning system based ground surveys. We will conduct a replicated experiment to determine the effect of excavation depth on the recovery rate of injured *Thalassia testudinum* meadows. We hypothesize that the severity of injuries to a *Thalassia* meadow will be a function of the depth of sediment excavated by the disturbance. NOAA/National Ocean Service/Office of Coastal Resource Management and National Centers for Coastal Ocean Science/CCFHR. [Summary of findings in annual report]

20) Steve Gilbert, U.S. Fish and Wildlife Service (Steve_Gilbert@fws.gov). FKNMS-2003-072, 10/20/2003 to 10/19/2004. Florida Keys Tidal Restoration Study. The goal of this project is to establish baseline conditions to enable detection of positive effects of flushing by potential construction of culverts or a bridge under U.S. Highway 1. U.S. Army Corps of Engineers, South Florida Water Management District.

21) Robert Glazer, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, (bob.glazer@fwc.state.fl.us). FKNMS-2001-055, 8/2/2001 to 8/31/2003. Survey and Rehabilitation of Queen Conch within the Florida Keys National Marine Sanctuary. The surveys include visual surveys of sites where conch are sparse, belt-transects of densely populated conch aggregations in offshore reef flats, tag-recapture sampling of nearshore conch aggregations, and sonic tagging experiments. Many of these surveys will be conducted within the Sanctuary Preservation Areas of the Florida Keys National Marine Sanctuary and are conducted as part of the marine zone monitoring surveys. The secondary goal of this research is to determine the spatial and temporal distribution of queen conch larvae in and around the different regions of the Florida Keys. This information will lead to determining the optimal release location of hatchery-reared or transplanted queen conch based upon the probability that conch larvae spawned in that location will recolonize the Keys. FWRI/FWC.

22) Walter Goldberg, Florida International University (goldberg@fiu.edu). FKNMS-2001-067, 8/29/2001 to 9/1/2003. Ultrastructure of Aggression in Corals of the Genus *Mycetophyllia*. This project will test the hypothesis that specialized regions occur at the tip of *Mycetophyllia lamarckiana* or *M. ferox* mesenterial filaments and are used during aggressive behavior. FIU.

23) Pamela Hallock Muller, University of South Florida (pmuller@marine.usf.edu). FKNMS-2003-002, 1/15/2003 to 12/31/2004. Larger Foraminifera as Bioindicators of Coral Reef Health: Continued Monitoring of Bleaching Stress, Comparison with an Integrated Molecular Biomarker System, and Temporal and Spatial Variability in Algal Symbionts. The reef-dwelling foraminifera, particularly *Amphistegina gibbosa*, have exhibited bleaching and associated symptoms on Florida Keys reefs since summer of 1991. This project will a) continue long-term monitoring of bleaching activity and its causes in larger foraminiferal populations of Florida Keys Reefs; b) complete a study that compares physiological responses and bleaching in *A. gibbosa*, to physiological responses in corals (*Montastraea* spp.) and other organisms being studied by Craig Downs, Cheryl Woodley and John Halas under separate permits; and c) determine if seasonal or spatial differences in algal symbiont populations influences bleaching in *A. gibbosa*. South Carolina Sea Grant Program; subcontract to USF.

24) Clay Harris, Middle Tennessee State University (cdharris@mtsu.edu). FKNMS-2002-003, 1/3/2002 to 12/31/2003. Baseline Assessment of Newfound Harbor Reef System, Big Pine Key, Florida. We propose to perform coral diversity assessments of the 3.8 km long linear reef and patch reefs seaward of the Newfound Harbor Keys, Big Pine Key, and the linear reef of unknown extent seaward of West Summerland Key in the FKNMS. We will investigate coral diversity, abundance, cover, and health using the Atlantic and Gulf Rapid Reef Assessment protocol -- a combined linear transect/random quadrat method -- with more thorough species presence/absence data collected using video transects. Sediment samples will be collected and classified according to grain type and size for comparison with other patch reef sites and existing data for NFHR (Dodd et al., 1973). MTSU grant.

25) John Hunt, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute (john.hunt@myfwc.com). FKNMS-2002-005, 1/7/2002 to 12/31/2004. Spiny Lobster Puerulus Monitoring Program. Influx of postlarval spiny lobsters is monitored using artificial settlement collectors that are placed in the nearshore waters on the Atlantic side of Long Key and Big Munson Key. We will replace the existing cinderblock anchoring systems with permanent, low profile stainless steel mooring eyes cemented into the substrate. FWRI base budget.

26) Claudia Jones, University of Pennsylvania (impglee@aol.com). FKNMS-2002-070, 8/23/2002 to 4/1/2003. The Effect of Climate Change and Rising Nutrient Levels on the Health of Selected Reefs in the Eastern Caribbean. Funding source unknown.

27) Sean Kinane, University of South Florida (skinane@helios.acomp.usf.edu). FKNMS-2003-009, 2/24/2003 to 12/31/2004. The Effects of Hydrodynamics on Coral Bleaching: Does Increased Flow Reduce Bleaching? Reduced bleaching is expected in high-velocity water flow based on field observations (e.g., Loya et al. 2001) and some experimentation (Nakamura and van Woesik 2001). This hypothesis will be tested in several coral species. The mechanisms of velocity-enhanced bleaching resistance will be explored including increased mass transfer of toxins out of corals in high flow. This research is partially supported by a 5-year NSF PECASE award to Dr. Thomas (OCE-9701434).

28) John Lamkin, NOAA Fisheries/Southeast Fisheries Science Center (john.lamkin@noaa.gov). FKNMS-2003-008, 2/24/2003 to 2/23/2004. Use of Geochemical Tracers to Elucidate Life History Trajectories of Gray Snapper within South Florida's Marine Ecosystems. It is our intent to map the source of recruits in the Florida Keys National Marine Sanctuary and the Tortugas Ecological Reserve using recent technological developments that allow us to detect trace elemental “fingerprinting” of fish otoliths. Commercially important snapper and grouper communities are believed to recruit to the reef from other areas, such as seagrass and mangrove habitats of Florida Bay, where they are believed to spend their juvenile phase before migrating to the coral reefs as young adults. We have established tentative "Florida Bay" signatures by collecting settled juveniles from the estuaries and now wish to establish "coral reef" signatures of adult fish taken from or adjacent to the coral reef SPAs and the reefs of the Tortugas Ecological Reserve. Comparing the two groups of otolith signatures will allow us to reconstruct the environmental history of individual fish. NOAA Coral Reef Initiative.

29) Brian Lapointe, Harbor Branch Oceanographic Institution (lapointe@hboi.edu). FKNMS-2003-003, 2/1/2003 to 1/31/2005. ECOHAB: Physiology and Ecology of Macroalgal Blooms on Coral Reefs off SE Florida. We propose to use the suspended line-bioassay, described and utilized previously at Looe Key by Littler et al. (1986) and Paul et al. (1987), to assess the consumption rates by grazing icthyofauna of resident macroalgae (scarids, acanthurids, etc.). Our interest is in performing these feeding preference studies at the shallow fore reef, reef crest, and rubble zone of the Looe Key "core area" and the patch reefs in Newfound Harbor Sanctuary Preservation Area (SPA), to calibrate the importance of nitrogen biochemistry of macroalgae to palatability by a functional reef icthyofaunal assemblage. EPA-ECOHAB program.

30) Tom Lee, University of Miami, Rosenstiel School of Marine and Atmospheric Science/MPO (tlee@rsmas.miami.edu). FKNMS-2001-006, 2/23/2001 to 2/28/2003. Florida Keys and Florida Bay Circulation and Exchange Project. This project continues work on current patterns and water circulation in the Florida Keys National Marine Sanctuary and Florida Bay that was initiated in 1989. South Florida Ecosystem Restoration, Prediction, and Modeling program under NOAA/COP (Yeung) and RSMAS/U. Miami (Lee).

31) James Leichter, Scripps Institution of Oceanography (leichter@coast.ucsd.edu). FKNMS-2002-035, 5/13/2002 to 12/31/2003. Responses of Benthic Macroalgae to High Frequency Upwelling on the Florida Keys Reef Tract. The goal of this project is to examine the consequences of high frequency nutrient upwelling for benthic macroalgal populations on and seaward of the Florida Keys reef tract. NOAA/National Undersea Research Center.

32) Niels Lindquist, University of North Carolina at Chapel Hill, Institute of Marine Sciences (nlindquist@unc.edu). FKNMS-2001-010, 3/15/2001 to 12/31/2003. Tracing Marine Sponge Responses to Environmental and Water Quality Gradients and Anti-Predator Defenses Among Marine Hydroids and File Clams. For "Tracing Marine Sponge Responses to Environmental and Water Quality Gradients" we will use natural abundance stable isotope analyses of sponges to provide a unique view of their nutritional ecology, including the contributions of their symbionts to their nutritional needs and to possibly measure the magnitude of symbiont inputs, the effect of water quality on sponge stable isotope values, and the source of bioactive compounds that protect many sponges against predators, competitors and pathogens. For "Anti-Predator Defenses of Marine Hydroids: Alternative Strategies, Biogeographic Patterns, and Ecological Implications", recent studies have demonstrated that hydroids can be defended from predators by two distinctly different mechanisms - stinging nematocysts or distasteful secondary metabolites. Data from our investigations will be used to rigorously test the hypothesis that trade-offs exists among defense systems, particularly in marine organisms. Our studies will also be used to examine the hypothesis that mesofauna abundance and diversity will be lower among nematocyst defended hydroids than among chemically defended hydroids because stinging nematocysts can harm associated mesofauna. For "Evolution of a Chemical Defense Among File Clams (Bivalvia: Limidae) - Relationships Between Bivalve Palatability, Shell Morphology, and Shell Strength", in general, chemically defended organisms lack physically protective structures. We are investigating the robustness of this relationship in using an unlikely group of animals to have a chemical defensive – i.e. bivalve molluscs. The Limidae bivalves are providing an excellent system to test evolutionary relationships among susceptibility to predators and the value of a physical vs. a chemical defense. Furthermore, with the ability to build molecular phylogenies

and an excellent fossil record, our data on extant Limidae and other bivalve species may provide a window into ecological and community structure of ancient reef habitats. An additional project, started in September 2002, is a subproject of the above research. Previous studies have shown that small epiphytic algae can alter the palatability of larger macrophyte to various herbivores. Given that marine hydroids are common epibionts on both marine plants and sessile invertebrates, we wish to test that hypothesis that epibiotic hydroids on seaweeds and seagrasses alter their palatability to herbivores. This hypothesis will be tested by offering individual urchins a choice between two pieces of the same seaweed species (mass measured at the beginning of the experiment) one with epibiotic hydroids and one lacking hydroids. The relative rates of herbivory on the two pieces will be statistically compared. This analysis will be run for various combinations of seaweed/seagrass-hydroid combinations. NURC/UNCW #2000-24, NSF (#0002723 and 0082049), and by UNC funding.

33) Diego Lirman, University of Miami/RSMAS (dlirman@rsmas.miami.edu). FKNMS-2002-075, 1/1/2003 to 12/31/2004. Coral Size-Frequency Distributions as Indicators of Reef Health: Monitoring and Modeling Approaches. This is the continuation of a previously permitted project that undertakes a demographic approach to assess the condition of coral populations within patch reefs of the FKNMS that incorporates individual-based parameters such as growth, survivorship, partial mortality, and fragmentation. These measures can reveal sublethal differences among populations that abundance and diversity measures alone may miss. Unsure of funding for 2003 and beyond.

34) Kevin Madley, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute (kevin.madley@myfwc.com). FKNMS-2001-020, 4/16/2001 to 4/15/2003. Florida Inshore Marine Monitoring and Assessment Program (IMAP). The goal of this project is to create a state-wide assessment of the environmental quality of inshore habitats by collecting information on various environmental indicators. The project is part of a long-term environmental monitoring program of over two dozen chemical, physical, and biological indicators under the U.S. EPA Coastal 2000 initiative. U.S. EPA Assistance Agreement #CR 827240-01-0.

35) Thomas Matthews, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute (tom.matthews@myfwc.com). FKNMS-2002-076, 1/1/2003 to 3/31/2003. The Evaluation of Marine Reserves as Sanctuaries for Caribbean Spiny Lobster (*Panulirus argus*). We propose to measure the age of spiny lobsters in the Western Sambo Ecological Reserve (WSER) by measuring the concentration of the pigment lipofuscin in the neural tissue of lobsters. This direct aging methodology should help determine the length of time lobsters are afforded protection in the WSER. National Fish and Wildlife Foundation Settlement Grant Agreement, project 1998-0249-005, Marine Reserves (FL) Evaluation for Spiny Lobster.

36) Mikhail Matz, University of Florida (matz@whitney.ufl.edu). FKNMS-2002-039, 5/31/2002 to 6/1/2003. Genetics, Ecology and Evolution of Coloration in Great Star Coral, *Montastraea cavernosa*. In reef-building corals each visually perceptible basic color is essentially determined by the sequence of a single protein, homologous to green fluorescent protein (GFP) from jellyfish *Aequorea victoria*. This provides a unique opportunity to address the question of color evolution in the environment directly by applying the tools of molecular phylogenetics designed

for sequence analysis and, in addition, to characterize and monitor variations in coloration in terms of expression of individual genes. The ultimate goal of the project is to understand the evolutionary mechanisms and ecological factors that determine the diversity of coloration in reef-building corals. UF/Whitney Laboratory.

37) Lisa Monk, Center for Marine Conservation (now The Ocean Conservancy) (Lmonk@vacmc.org). FKNMS-2002-022, 4/19/2002 to 12/31/2003. RECON (Reef Ecosystem Condition) Program. RECON is a low-tech, rapid monitoring protocol for volunteer divers. RECON divers are trained by CMC-certified RECON instructors to collect information on the condition of coral reef ecosystems. The goals of RECON are to broaden the scope of available information about the benthic organisms on coral reefs, to alert local reef researchers and managers of changing reef conditions (e.g., mass bleaching events, outbreaks of disease, nuisance algal blooms, changes in abundance of key mobile invertebrates), and to increase public understanding of the threats to coral reef ecosystems. U.S. EPA grant.

38) Leonid Moroz, University of Florida (moroz@whitney.ufl.edu). FKNMS-2001-058, 9/10/2001 to 12/31/2003. Coral Screening Project. This project is designed to screen a wide sampling of corals to accomplish two goals from one collection. First, we want to see if any local corals contain yellow or red fluorescing proteins. Second, we want to search for the presence of the enzyme nitric oxide synthase, which generates the gaseous messenger molecule nitric oxide. University of Florida.

39) Alison Moulding, University of Miami, Rosenstiel School of Marine and Atmospheric Science (amouldin@rsmas.miami.edu). FKNMS-2002-014, 4/1/2002 to 3/31/2003. Coral Recruitment in the Florida Keys and the Relationship Among Adult Abundance, Larval Supply, and Recruitment of *Porites astreoides*. The objectives of this study are to examine coral recruitment along the Florida reef tract and to explore the relationship among presence of adult colonies, fertilization success, and recruitment of juveniles of one species of coral common in the Florida Keys: *Porites astreoides*, a hermaphroditic, brooding coral. By including Florida Keys reefs in this study, a better understanding of the mechanisms of supply and recruitment can be obtained. RSMAS and RSMAS Founders Research Fund award.

40) Alison Moulding, University of Miami/RSMAS (amouldin@rsmas.miami.edu). FKNMS-2002-077, 1/1/2003 to 12/31/2005. The Role of Restoration in the Recovery of Coral Reefs from Vessel Groundings. This study will examine reef sites damaged by boat or ship groundings and control sites. Some of the damaged sites have undergone restoration, and some have been left to recover naturally. Ecological benchmarks, such as coral recruitment, percent cover of major benthic groups, and three-dimensional structural complexity, will be used to evaluate the reef communities present at the sites and the efficacy of restoration efforts. Biscayne National Park, Cooperative Agreement CA 5250-8-9036.

41) Erich Mueller, Mote Marine Laboratory (emueller@mote.org). FKNMS-2002-013, 3/1/2002 to 2/28/2003 and FKNMS-2003-005, 3/1/2003 to 2/29/2004. Effect of Mosquito Control Pesticides on *Porites astreoides* Planula Larvae. This study aims to determine how mosquito adulticides affect the survival and viability of planula larvae from the scleractinian coral, *Porites astreoides*. Larval responses will be assessed following exposure to the mosquito adulticides,

Naled and Permethrin, individually and combined, to simulate synergistic responses. Larvae will be dosed over a lethal and sublethal concentration range and a variety of endpoints recorded. Mote Marine Laboratory Research Fellowship.

42) Gregory Piniak, NOAA/NOS, Center for Coastal Fisheries and Habitat Research (gregory.piniak@noaa.gov). FKNMS-2002-087, 9/1/2002 to 2/28/2003. Fluorescence as a Tool for Enumerating Coral Recruits. Fluorescence technology is useful in locating coral recruits and other small reef organisms that are difficult to detect with the naked eye. We propose a study to determine the capability of fluorescent technologies to identify and enumerate coral recruits, and to rigorously compare these techniques with current methods used to quantify coral recruitment on natural and artificial substrates. NOS.

43) Patrick Pitts, U.S. Fish and Wildlife Service (patrick_pitts@fws.gov). FKNMS-2002-036, 5/13/2002 to 5/12/2003. Florida Keys Tidal Restoration. The Florida Keys Tidal Restoration Project, a component of the Comprehensive Everglades Restoration Plan, is designed to restore tidal circulation in the middle Florida Keys in order to improve water quality and the health and composition of flora and fauna in the project area. The U.S. Fish and Wildlife Service (USFWS) will to provide guidance to the U.S. Army Corps of Engineers, the agency in charge of project construction, regarding ecological and environmental concerns, including threatened and endangered species. In order to provide this guidance, the USFWS will need to conduct field surveys to determine fish and wildlife resources in the project area. Fish and Wildlife Coordination Act transfer funding from the U.S. Army Corps of Engineers.

44) Terrence Quinn, University of South Florida (quinn@marine.usf.edu). FKNMS-2003-070, 10/16/2003 to 12/31/2003. Coral-Based Reconstruction of Environmental Variability in the Surface Waters of the Dry Tortugas. Our aim is to generate a >100-year environmental record of sea-surface variability from a coral core extracted from a live *Montastraea annularis* from Tortugas Bank. Our ultimate goal is to assess the range of natural climate variability over the past ~ 10,000 yr based on a quantitative comparison between modern and fossil coral-based climate records. The fossil corals have already been collected; it is now time to collect a modern coral so that our study can proceed. National Science Foundation, OCE-0221750.

45) Laurie Richardson, Florida International University (richardl@fiu.edu). FKNMS-2003-011, 3/5/2003 to 3/31/2005. Distribution and Etiology of Two Coral Diseases in the Florida Keys National Marine Sanctuary: Black Band Disease and White Plague Type II. This research constitutes continuation of our work on coral diseases in the FKNMS, and specifically addresses several hypotheses which have grown out of our work and which directly address both overall and specific objectives outlined in the Water Quality Protection Program. Unknown.

46) Susan Richardson, Smithsonian Marine Station at Fort Pierce (richardson@sms.si.edu). FKNMS-2002-008, 2/11/2002 to 12/31/2003. Diversity, Distribution, and Abundance of Foraminiferans in Seagrass Habitats, Florida Keys. Benthic foraminiferans, both epiphytic and sediment-dwelling, will be sampled from seagrass habitats in the Florida Keys. The diversity, distribution, and abundance of foraminiferal faunas will be characterized and compared and contrasted to similar sites in the Indian River Lagoon and Belize. Smithsonian Institution Postdoctoral Fellowship.

47) William Sharp, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute (bill.sharp@fwc.state.fl.us). FKNMS-2003-007, 2/21/2003 to 12/31/2003. The Effect of Sea Urchin Herbivory on a Subtropical Seagrass Community: Experimental Manipulations Within a Manatee Grass-Dominated Meadow in South Florida. In an effort to increase our understanding of the dynamics of urchin herbivory within the Florida Keys National Marine Sanctuary, we propose a series of manipulative field experiments designed to examine the effects of herbivory by *Lytechinus variegatus* on *Syringodium filiforme*. Using cages placed in situ within a large *S. filiforme* meadow, we will manipulate urchin densities and quantitatively assess their effects upon seagrass biomass. Florida Fish and Wildlife Conservation Commission and NOAA/Coastal Ocean Program.

48) Ned Smith, Harbor Branch Oceanographic Institution (nsmith@hboi.edu). FKNMS-2002-063, 9/16/2002 to 9/30/2003 and FKNMS-2003-067, 10/1/2003 to 4/30/2005. Nutrient Mass Fluxes between Florida Bay and the Florida Keys National Marine Sanctuary through Florida Keys Passes. Current speed/direction and water level will be measured to estimate volume transport through Long Key Channel and Moser Channel. Volume transports will be combined with nutrient concentrations to calculate nutrient transport. Measurements made during this field study will quantify the magnitude and direction of seasonal and long-term net nutrient transport between Florida Bay and Hawk Channel. NOAA/Coastal Ocean Program.

49) Keith Spring, Continental Shelf Associates, Inc. (kspring@conshelf.com). FKNMS-2003-071, 10/22/2003 to 7/1/2005. Resource Health and Sedimentation Monitoring and Resource Impact Assessment Monitoring for the Key West Maintenance Dredging Project. The proposed monitoring for the Key West Maintenance Dredging Project is being conducted to protect and minimize impacts to marine resources in the vicinity of the project area. Coral and seagrass health measurements will be made at specific locations adjacent to the project area and used as indicators of potential dredging impacts. Repetitive video transects will also be established pre- and post-construction to assess dredging impacts. Sedimentation data will be collected at weekly and monthly intervals. U.S. Navy in association with the dredging contract for the project.

50) Colette St. Mary, University of Florida (stmary@zoo.ufl.edu). FKNMS-2001-019, 5/1/2001 to 5/1/2003. The Effects of Artificial Reef Habitats on Fish Production. The goal of this project is to quantify the net effect of new habitat on fish production, enhance the sustainability of the marine ornamental fishery, and directly test the attraction-production hypotheses. To successfully conduct the critical field experiment, we need to optimize its design, which will depend upon patterns of spatial and temporal variance in settlement and abundance, the strength of density-dependence and the degree of movement between the artificial and natural reefs (as well as diffusion among the natural reef habitat). We will accomplish this by integrating field studies, quantitative literature syntheses, and mathematical population dynamic models. National SeaGrant Program.

51) Peter Swart, University of Miami, RSMAS (pswart@rsmas.miami.edu). FKNMS-2000-018, 4/3/2000 to 12/31/2003. The Origin and Recycling of Nutrients and an Investigation of Trophic Dynamics. The research proposed here is designed to generate an integrated data set, combining work on the sources of nutrients (Swart), cycling and fates of nitrogen and carbon (Swart and

Szmant), nutrient flux and interactions with currents (Lee), the production of organic material by algae (Szmant) and energy flow between trophic levels (Cowen and Sponaugle). National Center of Caribbean Coral Reef Research.

52) Alina Szmant, University of North Carolina at Wilmington (szmanta@uncwil.edu). FKNMS-2002-054, 6/17/2002 to 6/30/2003. Research on Nutrient Dynamics, Algal Community Structure, and Algal Productivity. Regional coral reef decline is indicated by rapid loss of coral cover and increases in algal cover. It is important to be able to distinguish between increased algal cover being a symptom of coral decline (e.g. algal colonizing substrate vacated by coral killed by one factor or another) vs. a causative factor (algae over-growing and killing the coral), especially if the latter is the result of anthropogenic nutrient enrichment of reef areas. Thus, a major objective of this NCORE subcontract will be to address factors that affect relative algal dominance. These include nutrient availability and cycling, and grazing pressure. National Center for Caribbean Coral Reef Research at the Univ. of Miami, funded by U.S. EPA. Subcontract to UNCW.

53) Florence Thomas, University of South Florida (fthomas@chuma1.cas.usf.edu). FKNMS-2002-041, 6/1/2002 to 12/31/2003. The Effects of Water Velocity/Hydrodynamics on Mass Transfer of Nutrients: a Partnership in Research and Education. This project explores the relationship between water velocity, nutrient uptake, and the morphology of the predominant community members of nearshore benthic communities, including seagrasses (i.e. *Thalassia testudinum*, *Halodule wrightii*) and macroalgae (i.e. *Halimeda* sp.). As the title implies, this NSF-funded project links research in hydrodynamics and biomechanics to public, k-12, undergraduate, and graduate education. Minority participation is encouraged at all levels and is the primary focus of recruitment at the undergraduate level. Supported by a 5-year NSF PECASE award to Dr. Thomas (OCE-9701434).

54) Linda Walters, University of Central Florida (ljwalter@pegasus.cc.ucf.edu). FKNMS-2003-076, 12/1/2003 to 11/30/2005. Killer Algae: Preventing Florida from Becoming the next Invasion Location of *Caulerpa taxifolia* -- Mediterranean strain. This project strives to determine whether DNA sequences of the native algae Caulerpa taxifolia and the invasive Mediterranean strain are significantly different. We will collect *Caulerpa* (green macroalgae) samples for DNA sequencing by Dr. Olsen's lab in the Netherlands. NOAA/National Sea Grant Aquatic Nuisance Species Program, administered by Florida Sea Grant.

55) Gerard Wellington, University of Houston (wellington@uh.edu). FKNMS-2002-081, 7/31/2002 to 8/31/2003. Genetic Variation and Phenotypic Response of *Montastraea faveolata*. The first, experimental project will estimate the heritability of metabolic and molecular characters related to stress response of *M. faveolata*. To date, heritability of both metabolic and molecular characters related to stress have not been investigated in any coral species. The purpose of the study will be to investigate the contribution of genetic vs. non-genetic (environmental and symbiont association) effects associated with *M. faveolata's* response to stress. The second project will be exploratory in nature. Currently, the genetic population structure for *M. faveolata* has not been investigated. The purpose of my project will be to collect preliminary data to test for significant genetic variation along the Florida Keys for *M. faveolata*. Houston Coastal Center.

56) Jennifer Wheaton, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute (jennifer.wheaton@myFWC.com). FKNMS-2001-015, 4/16/2001 to 12/31/2003. Coral/Hardbottom Monitoring Project. The coral/hardbottom monitoring project documents status and trends (change) in stony coral species presence and percent cover of selected attached reef benthos. Documentation of degree of bioerosion will be a subset of the project beginning summer 2001. Established in 1995, the project's 43 sampling sites, which include 7 hardbottom, 11 patch, 12 offshore shallow, and 13 offshore deep reef sites are sampled annually. The project's primary goal is to document change in the presence/absence of stony coral species richness and selected disease categories and relative percent cover of corals, octocorals, sponges, macroalgae, and substrate. U.S. EPA, FKNMS. [Summary of findings in annual report]

57) Cheryl Woodley, NOAA National Ocean Service, National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Environmental Health & Biomolecular Research (cheryl.woodley@noaa.gov). FKNMS-2001-008, 4/1/2001 to 4/30/2003. Assessment of Coral Health in the FKNMS Using a Molecular Biomarker System (MBS). We have developed a Molecular Biomarker System (MBS) capable of determining whether corals are stressed and causative agents associated with that stress. The MBS works because the biomarkers respond to stress along biochemical and cellular pathways common to all organisms, from bacteria and protists to plants and higher animals. National Sea Grant Consortium collaborators include NOAA/NOS/NCCOS, Med. Univ. of South Carolina, FKNMS, Biscayne National Park, Univ. of South Florida, Univ. of Charleston, Coral Shores High School, and EnVirion Biotechnologies, Inc. These specific proposed projects are a subset of larger proposed projects to National Sea Grant and U.S. EPA and form a collaboration between the National Marine Sanctuary Program and NCCOS. [Summary of findings in annual report]