The State of Coral Reef Ecosystems of the Florida Keys

Scott Donahue[1], Alejandro Acosta[2], Lad Akins[3], Jerald Ault[4], James Bohnsack[5], Joseph Boyer[6], Michael Callahan[2], Billy Causey[1,9], Carrollyn Cox[2], Joanne Delaney[1], Gabriel Delgado[2], Kent Edwards[1,7], George Garrett[8], Brian Keller[9], G. Todd Kellison[5], V. Robert Leeworthy[10], Lauri MacLaughlin[1], Loren McClenachan[11], Margaret W. Miller[5], Steven L. Miller[12], Kim Ritchie[13], Steven Rohmann[10], Deborah Santavy[14], Christy Pattengill-Semmens[3], Benjamin Sniffen[1], Stephen Werndli[1] and Dana E. Williams[5]

INTRODUCTION AND SETTING

In this chapter, the authors present the latest in a series of updates to this living document. The 2005 edition of this report provided a good basis for this update, as it nicely detailed the coral reefs of the Florida Keys and southeast Florida, along with their associated oceanography, reef geomorphology and geology, and socioeconomic importance (Andrews et al., 2005). This edition of the report provides two separate chapters for the coral reefs of Florida in appreciation of their separate regulatory histories and the different reef types present in the Florida Keys and the Southeast region. The two chapters will complement each other and should be used to highlight the challenges associated with managing a coral reef ecosystem that extends over 480 km (300 miles). Contributing authors for the Florida chapter in Waddell (2005) were contacted for this chapter and only those updates available at the time of this writing were included. Manuscripts and information that were in preparation will be included in the next edition of this volume. Figure 6.1 highlights locations mentioned throughout this chapter.

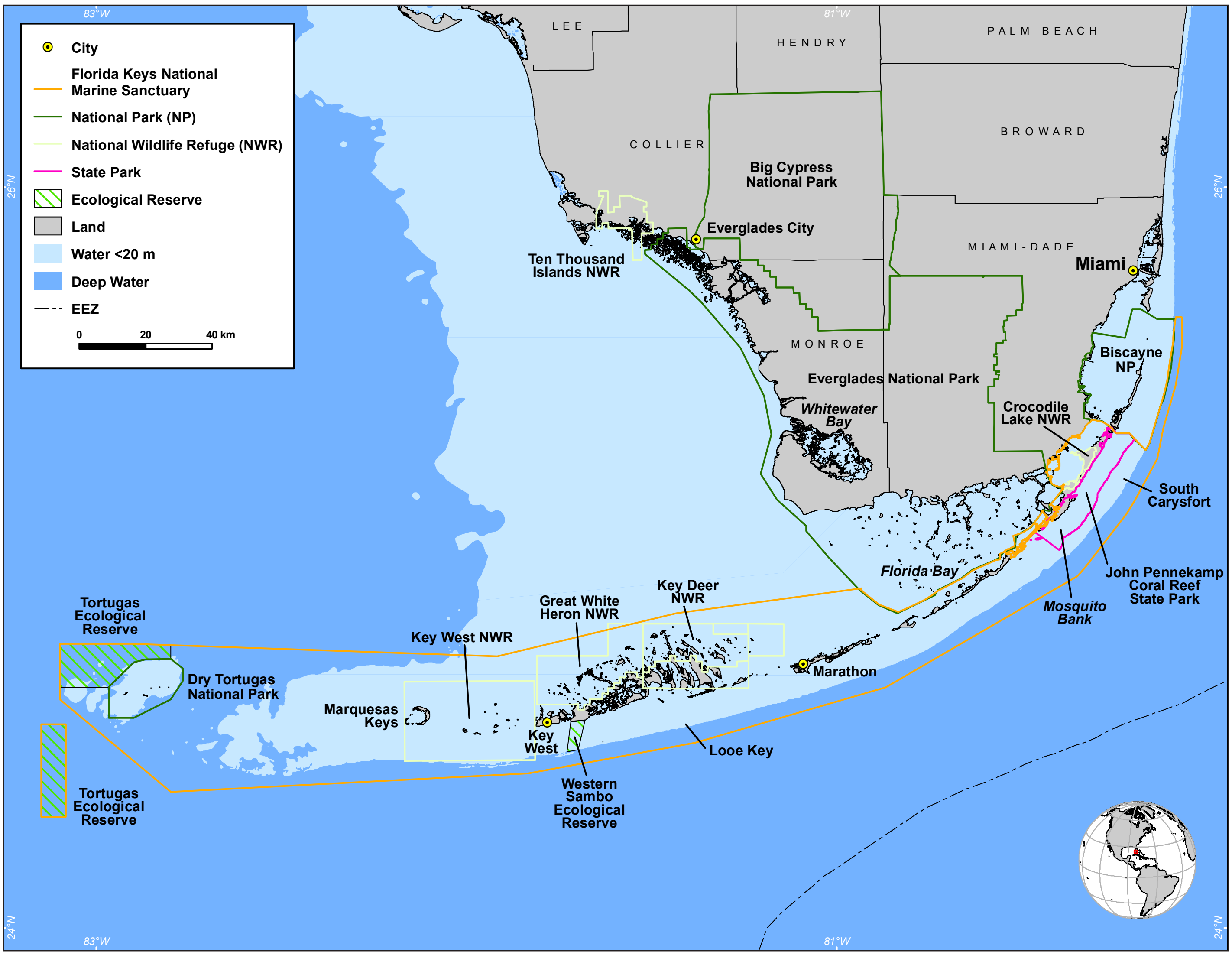

Figure 6.1. Locator map of the Florida Keys depicting locations mentioned in this chapter. Map: K. Buja.

1. NOAA, Florida Keys National Marine Sanctuary
2. Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute
3. Reef Environmental Education Foundation
4. University of Miami, Rosenstiel School for Marine and Atmospheric Science
5. NOAA, Southeast Fisheries Science Center
6. Florida International University, Southeast Environmental Research Center
7. Florida Department of Environmental Protection
8. Monroe County Division of Marine Resources
9. NOAA, Office of National Marine Sanctuaries
10. NOAA, National Ocean Service, Special Projects Office
11. Scripps Institute of Oceanography
12. University of North Carolina, Wilmington
13. Mote Marine Laboratory
14. U.S. Environmental Protection Agency, Gulf Ecology Division9.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Although elevated sea surface temperatures (>31°C) returned to the Florida Keys in 2004 and 2005, only minor to moderate coral bleaching was observed in patchy patterns on the coral reefs. While severe coral bleaching events were observed and recorded in other parts of the U.S. Caribbean, the Florida Keys escaped most of the stressful environmental conditions experienced elsewhere. Due to an active hurricane season both in 2004 and 2005, extended periods of doldrum-like weather patterns did not establish in the Florida Keys. The passage of each tropical storm or hurricane decreased sea surface temperatures, as well as allowing for mixing of the surface waters due to intense winds.

Figure 6.2 shows how the waters cooled off just after the passage of three hurricanes in the Florida Keys in 2005. Illustrated are the 2004 and 2005 sea surface temperatures that were recorded at a SeaKeys C-Man station established at Sombrero Reef located on the reef tract off the middle Florida Keys. In 2005, elevated sea surface temperatures (>31ºC) were present between July and September 2005. Doldrum-like weather patterns persisted for most of the time and corals began to bleach and show signs of stress. Before a mass bleaching event occurred, the passage of Hurricanes Katrina, Rita and Wilma alleviated the stressful conditions of elevated sea surface temperatures and doldrum weather patterns. More information on the effects of bleaching on reefs in the Florida Keys can be found in the Benthic Habitats section of this chapter.

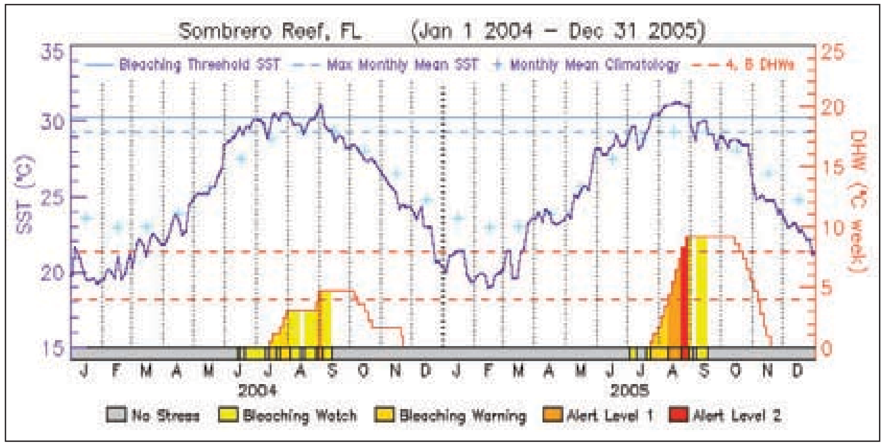

Figure 6.2. Sea surface temperatures (SST) recorded at Sombrero Reef in the Florida Keys between January 2004 and December 2005. Passage of hurricanes Katrina, Rita and Wilma in September and October 2005 alleviated the stressful conditions of elevated sea surface temperatures and doldrum weather patterns. DHW=Degree Heating Weeks. Source: NOAA/ NESDIS.

Diseases

Corals throughout the Caribbean and Atlantic region have suffered from numerous diseases over the past several decades, and disease has been implicated in the demise of a number of reef building species. Two studies in the Florida Keys track disease prevalence at monitoring stations throughout the archipelago. In one study, the prevalence of diseases has been shown to vacillate over time, and since 2002 has generally decreased at monitored stations within Florida Keys National Marine Sanctuary (FKNMS) and at the Dry Tortugas. Because diseases can be difficult to distinguish in the field, this study grouped white diseases (white plague, white pox, white band) to differentiate them from black band disease, while the remainder of disease states fell into an "Other" category. The number of stations affected with white diseases peaked to more than 80% in 2002, subsided to 35% in 2005, then increased again to 50% in 2006. The number of stations affected with Other diseases peaked to 90% in 2001, but declined to 57% by 2006. The other reported study, which was conducted in August of 2006, focused on diseases affecting two species of coral that had been recently listed as threatened on the U.S. Endangered Species List: *Acropora cervicornis* and *A. palmata.* The group surveyed 107 sites along about 46 km of coastline in the upper keys and fortunately found no evidence of white band or other diseases affecting either species. More information on the effects of coral diseases on reefs in the Florida Keys can be found in the Benthic Habitats section of this chapter.

Tropical Storms

Tropical cyclones are an annual threat to Florida coastal ecosystems and may impose a variety of devastating effects, including storm surge, freshwater flooding due to excessive rainfall and damaging winds. The 2005 hurricane season had very serious impacts to Florida coastal resources, whereas the 2006 and 2007 seasons produced more minor, localized impacts (Figure 6.3). The record-breaking 2005 Atlantic Hurricane Season produced a total of 28 named tropical storms, 15 of which attained hurricane strength throughout the Atlantic, Caribbean Sea and Gulf of Mexico. Of these storms, five tropical cyclones directly impacted the Florida Keys, with a frequency of one storm per month. Tropical Cyclone Arlene, the first one to affect Florida Keys in 2005, passed west of Dry Tortugas before making landfall west of Pensacola in early June. Hurricane Dennis passed over Dry Tortugas approximately one month later, causing severe erosion from west of John Pennekamp State Park through the Dry Tortugas. Compared with the other tropical cyclones to affect the Florida Keys in 2004 and 2005, Dennis was noted by FKNMS resource managers for its powerful hydrodynamic energy. Approximately a month and a half later, Hurricane Katrina struck south Florida as a Category 1 hurricane in late August. Only minor wind and storm surge damage was reported throughout mainland south Florida, however, rainfall in excess of 10 inches produced major freshwater flooding southwest of Miami and throughout the Lower Florida Keys. As Katrina passed over the Dry Tortugas, only minor overwash of the sand beaches and docks was reported. Hurricane Rita passed south of the Florida Keys in late September. While minor wind damage and no freshwater flooding was reported, significant storm surge flooding in excess of 5 ft above normal was reported along Atlantic-facing shores of the Keys, producing widespread overwash of sand beaches. The last tropical cyclone to affect Florida in 2005 was Hurricane Wilma, which was the most devastating to the Florida Keys. Wilma struck the coastline of extreme southwest Florida, south of Everglades City, in late October as a major hurricane. Widespread storm surge reached 8 ft above normal and completely overwashed most of Florida Keys from Marathon westward, with storm surge likely in excess of 8 ft across the Everglades coastline south of Everglades City. Severe wind damage was also noted in the Key West National Wildlife Refuge in the Marquesas Keys, with numerous mangrove branches snapped and some plants completely uprooted. While damage to mangrove forests resulted in some displacement of local bird populations, sand deposition on beaches may have benefited turtles nesting in the Keys. The 2006 hurricane season included two landfalls in Florida: Tropical Storm Alberto along the Big Bend coastline in June, and Hurricane Ernesto (which soon weakened to tropical storm intensity) which swept across the Florida Keys and southwest Florida in August. Ernesto did not produce significant coastal erosion in the Florida Keys.

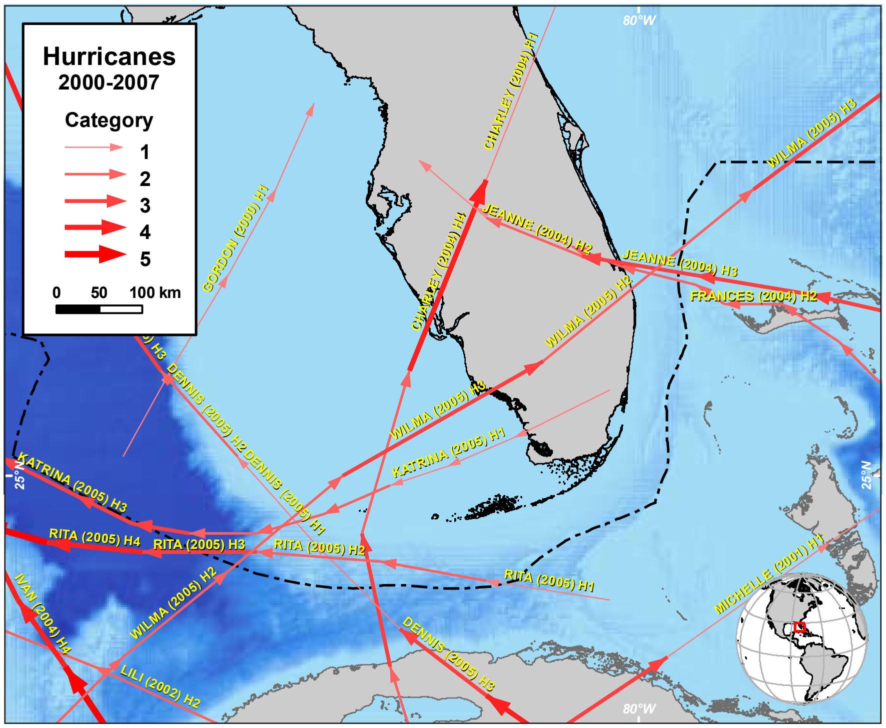

Figure 6.3. The paths and intensities of tropical storms affecting the Florida Keys, 2000-2007. Storm name, year and strength are indicated for each. Map: K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.

Damage and destruction resulting from tropical cyclones are usually thought of in terms of land-based observations. However, the marine ecosystem is always affected by these storms as well. Many marine habitats surveyed in the Dry Tortugas region suffered obvious physical damage (e.g., overturned coral colonies) and scouring from the storms that hit the region in 2005. Many areas that were gorgonian-dominated hard-bottom habitats in 1999-2000 and 2002, especially in the southern portion of Dry Tortugas National Park (DTNP), are now devoid of most gorgonians and sponges. Interestingly, concurrent reef fish surveys documented a marked decline in the abundance of juveniles of some species (e.g., black grouper) that were previously relatively abundant in these habitats. Reef terraces on Little Tortugas Bank and the northwestern Tortugas Bank (Sherwood Forest) are still in relatively good condition in terms of coral abundance, but coral cover has apparently declined from about 50% to about 35% in some areas. In these same sites, scientists noticed an increased prevalence of the brown alga *Lobophora variegata* that now occupies space once covered by live coral. A few sites also exhibited relatively high prevalence of coral disease, especially by what is believed to be white plague. At one site in particular, approximately 25% of the corals were afflicted with this condition. The factors responsible for increasing disease prevalence are unknown. The hypothesis that coral bleaching and other stressors increase susceptibility to disease needs to be tested. However, the extent, severity and degree of recovery from coral bleaching that occurred in 2005 are unknown.

Relative to 1999-2000, June 2006 sampling efforts revealed that sea urchins, especially *Diadema antillarum*, were more abundant and were found in relatively dense aggregations (>0.3 individuals/m^2) in some of the shallow water patch reef, hardbottom and medium-profile reef areas in DTNP (Miller et al., 2006a). While *Diadema* densities are still below the estimated historical (pre-1983) densities (approximately 1 individual/m^2 for certain habitat types), urchin densities in the Tortugas region, especially within DTNP, remain about an order of magnitude higher than levels documented in the rest of the Florida Keys. An increase in the number of recently recruited juvenile *Diadema* in the region is encouraging; peak recruitment in south Florida normally occurs during August and September. Of the 98 *Diadema* recorded at 46 monitoring sites, about 75% measured less than 1 cm in test diameter and were believed to have settled in the previous two months.

Coastal Development and Runoff

A major influence on water quality in Florida Bay and the Keys is runoff from south Florida and the Everglades. In the later third of the 20th century, it was recognized that modifications to drainage of fresh water in the south Florida region resulted in serious environmental effects. The drainage system, known as the Central and Southern Florida Project (C&SF), was constructed by the U.S. Army Corps of Engineers (USACE) and was the focal point of the south Florida water management system for the past 50 years. The Water Resource Development Acts of 1992 and 1996 provided the USACE with the authority to review the C&SF, and to develop a comprehensive plan to restore and preserve the south Florida ecosystem by enhancing fresh water flow into the Everglades while maintaining flood protection in the surrounding areas. In April 1999, the Comprehensive Everglades Restoration Plan (CERP) was finalized, which detailed more than 60 major changes to fresh water delivery that needed to occur in and around the Florida Everglades. If implemented, these changes will affect an area of more than 18,000 square miles. More information on CERP can be found at http://www.evergladesplan.org/index.aspx.

Coastal development also affects nearshore water quality in the Florida Keys, and as a result, Monroe County has developed Master Stormwater and Wastewater Plans (MSWWW) designed to comprehensively address the significant local sources of pollution in Florida Keys waters. Construction has been completed on some of the MSWWW projects and several others have been initiated. Additionally, the state of Florida has mandated that all homes and businesses in Monroe county be hooked up to centralized sewage treatment plants (the wastewater portion of the MSWWW) by the year 2010, thus the county government is actively seeking funding from several sources to meet this aggressive schedule. There are also several local, state and federal regulatory programs in place that were designed to reduce and mitigate the impacts of upland development on natural habitats and coastal water quality. More information about these programs can be found on the Internet for Monroe County (Rate of Growth Ordinance, Section 9.5-120 Monroe County Code http://www.municode.com/resources/gateway.asp?sid=9&pid=11270) and state and federal wetlands and surface water (http://www.dep.state.fl.us/water/wetlands/erp/index.htm).

In an effort to keep the beach-going public informed about water-borne microorganisms that could cause disease, infections or rashes, the Florida Department of Health monitors water quality at a number of beaches in 34 coastal counties. Monroe County has 17 beaches that are tested weekly for *Enterococci* and fecal coliform bacteria. High concentrations of these bacteria prompts the issuance of health advisories or warnings for that week. There were 884 beach weeks tested in Monroe County in 2006 (17 beaches x 52 weeks), ninety of the tests (about 10%) resulted in advisories and warnings. Additional information about beach water quality for the Florida Keys can also be found at http://esetappsdoh.doh.state.fl.us/irm00beachwater/default.aspx?county=Monroe.

Coastal Pollution

In addition to the information presented in the Costal Development and Runoff section above, please refer to the Southeast Florida chapter of the 2005 edition of this report (Andrews et al., 2005) for further information.

Tourism and Recreation

Artificial reefs have previously been deployed in the Florida Keys (e.g., at Adolphus Busch, Thunderbolt, Duane, etc.). In 2000-2001, Johns et al. (2001) estimated that both residents and visitors of the Florida Keys spent 1.58 million person-days snorkeling, SCUBA diving and fishing on the artificial reefs in the FKNMS. This activity generated over $131 million in output/sales, $31 million in income, and 2,365 full and part-time jobs in Monroe County. In addition, the artificial reefs had an estimated net annual user value of $9.75 million with an asset value of $57.5 million. Residents and visitors were willing to pay annually an additional $2 million for new artificial reefs.

The FKNMS currently has a moratorium on deployment of additional artificial reefs, with the exception of the USS *Vandenberg*, which was given approval by National Oceanic and Atmospheric Administration (NOAA) and FKNMS in 2003 and is scheduled to be placed in mid-2008. The moratorium was enacted because of concerns about whether artificial reefs will harm or help the natural reefs in the FKNMS.

In June 2002, the retired navy ship USS *Spiegel Grove* was sunk in the waters off Key Largo in the FKNMS. At 510 ft, the *Spiegel Grove* was at the time the largest vessel ever intentionally sunk for the purpose of creating an artificial reef within the FKNMS. Proponents of the *Spiegel Grove* argued that the ship's role as an artificial reef would take pressure off the surrounding natural reefs and thus provide an ecological benefit. Leeworthy et al. (2006) tested this hypothesis over a 10-month period via a pre- and post-sinking monitoring effort. A combination of dive shop logbooks and on-water observation were used to estimate total use on the artificial and natural reefs surrounding the area where the *Spiegel Grove* was to be sunk. The study found that after the sinking of the *Spiegel Grove*, usage of surrounding natural reefs declined 13.7%, while use of artificial reefs increased 160.5% and total reef use (artificial and natural) increased 9.3%. In addition, dive shop business increased 3.7% and total recreation and tourism increased as well, resulting in an additional $2.7 million in total sales/output, $962,000 in income and 68 full and part-time jobs in the Monroe County economy.

Additional visitor and resident surveys to track the use of Florida Keys reefs and associated economic benefits are scheduled to be conducted in 2008 and summary results and reports are expected to be available according to the schedule in Table 6.1. More detailed analysis of the data, which requires more time to analyze, review and publish, will be included in future versions of this report as it becomes available.

Table 6.1. Schedule of completion for the Florida Keys Visitor Survey reports. Source: V.R. Leeworthy.

AVAILABLE	REPORT
April 15, 2009	Visitor Profiles Report
May 15, 2009	Visitor Economic Contribution Report
June 15, 2009	Visitor Importance - Satisfaction Ratings Report
June 15, 2009	Resident Survey Report: Profiles, Economic Contribution and Importance-Satisfaction Ratings
July/August 2009	Visitor and Resident Survey: Knowledge, Attitudes and Perceptions of Sanctuary Management Strategies and Regulations

Knowledge, Attitudes and Perceptions of Regulations and Management Strategies in the FKNMS

In 2005, NOAA funded replication of a baseline study completed in 1995-1996 by researchers at the University of Florida and the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences through a Florida Sea Grant Project. Baseline information was obtained on the knowledge, attitudes and perceptions about regulations and management strategies being proposed for the FKNMS and the no-take areas established in 1997. The baseline and 10-year replication will assess changes in the knowledge, attitudes and perceptions of FKNMS regulations and management strategies for three user groups: commercial fishermen, dive shop owners and operators and members of local environmental groups. Surveys of commercial fishermen and dive shop owners/operators were completed in 2006. A 100% response rate was achieved on a random sample of 300 commercial fishing operations, and a 95% response rate was achieved for all 65 dive shop owners/operators in the Florida Keys in 2006. The survey of members of local environmental groups began in December 2006 and was completed in May 2007. Analyses and reports are expected to be available by 2008. For more information about ongoing socioeconomic research, visit http://marineeconomics.noaa.gov/welcome.html.

Fishing

Both recreational and commercial fishing occur regularly in Florida Keys waters. From a recreational standpoint, fishers are either local residents (roughly one third of Florida's total population of approximately 18 million people live in Southeast Florida or the Keys) or non-residents visiting "The Fishing Capitol of the World," as the state of Florida promotes itself (Ault et al., 2005a; FWC, 2007).

Total fishing activity in the Florida Keys reflects Florida's increasing population, which grew tenfold from 1930 to 2007 (Ault et al., 2005b). Recreational vessel registrations in Monroe County increased more than 1000% from 1964 to 2006, while commercial vessel registrations increased by about 100% from 1964 to 1998 but have since decreased by 37% (Bohnsack, et al., 1994; Figure 6.4). Precise data on fishing effort on coral reefs do not exist, but are reflected by statewide and regional fishing statistics. In the five most recent years for which recreational fishery estimates are available (2001-2005) for Florida, more than 6.4 million anglers averaged 27.2 million marine fishing trips annually. An estimated 173.3 million fish were caught annually, of which slightly more than 50% were released (86.9 million; NMFS, 2007). Two recent (2000-2001, 2003) non-concurrent studies showed that 3.64 million person days were spent fishing on natural reefs annually in the Florida Keys (Johns et al., 2001; Johns et al., 2004). Concomitant with increasing fishing pressure associated with increasing population, average fishing power (the proportion of stock removed per unit of fishing effort) may have quadrupled in recent decades because of technological advances in fishing tackle, hydroacoustics (depth sounders and fish finders), navigation (charts and global positioning systems), communications and vessel propulsion (Bohnsack and Ault, 1996; Mace, 1997).

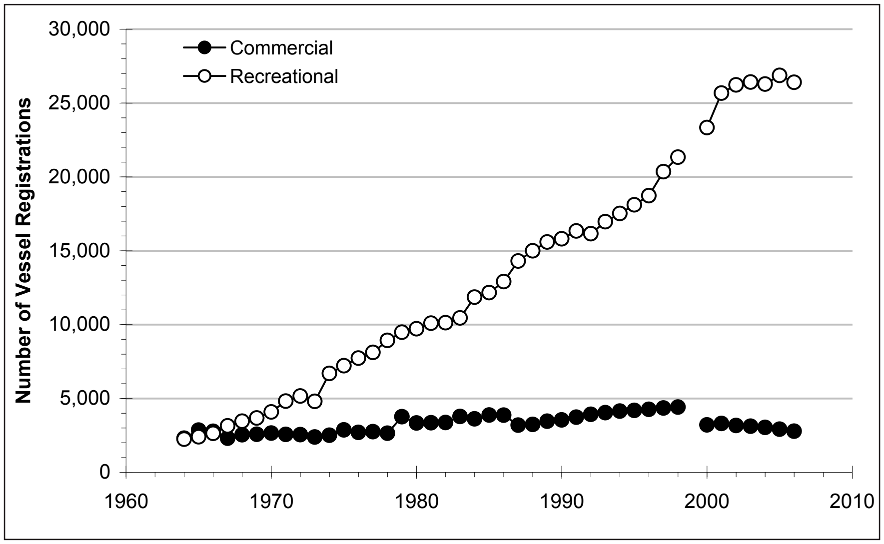

Figure 6.4. Southern Florida (Monroe, Dade, Broward, Palm Beach and Collier Counties commercial and recreational vessel registrations from 1964 to 2007. Sources: Florida Statistical Abstracts and Florida Department of Highway Safety and Motor Vehicles.

Fishing can stress coral reefs by removing targeted species and by killing nontarget species as bycatch, both of which may result in cascading ecological effects (Frank et al., 2005). Because fishing is size-selective, concerns exist about ecosystem disruption by removal of ecologically important keystone species, top predators (e.g., groupers, snappers, sharks and jacks), and prey (e.g., shrimps and baitfish).

Fishing can also negatively impact reef ecosystems via fishing-related habitat damage. Commercial fisheries for lobsters and stone crabs in the Keys utilize traps that are deployed in habitats adjacent to reefs. Strong storms can move traps onto reefs, where corals and other benthic organisms are damaged or killed (e.g., Sheridan et al., 2005). In 2005, approximately 300,000 lobster traps were believed to have been lost during a series of hurricanes and strong storms (Clark, 2006). Many reefs throughout the Keys are littered with lost traps and with monofilament line lost by recreational anglers. Reef damage may also occur from anglers anchoring on reefs (Davis, 1977). Finally, stress associated with fishing-related removal of species and habitat damage may be compounded when combined with other stressors such as pollution and climate change (Wilkenson, 1996).

Trade in Coral and Live Reef Species

The trade in coral and live reef species is not considered a major direct threat to coral reef ecosystems in Florida. The collection and sale of living corals and hard substrate with attached organisms ("live rock") has been prohibited in state waters of Florida since 1995 and in federal waters since 1997. The state and federal government both regulate a small but viable fishery based in live rock aquaculture, where geologically-unique limestone is placed on the ocean floor and acts as a recruitment site for hard and soft corals and other marine invertebrates. While the fishery remains commercial in nature (mature live rock is sold in the aquarium trade), opportunities to use aquacultured live rock for mitigation or restoration may exist in the future.

Similar to live rock aquaculture, the collection and sale of live reef species comprises a small but well-managed fishery, most notably in the Florida Keys. Approximately 147 endorsements (permits) were issued for the live collection of ornamental vertebrates and invertebrates for sale in the aquarium industry in Monroe County in 2007. State-wide landings in 2005 included 147,290 total finfish and 8,611,912 individual invertebrates (e.g., polychaete worms, tunicates, crabs, sea stars and anemones). The fishery has been regulated by the state fisheries agency (currently the Florida Fish and Wildlife Conservation Commission or FWC) since 1991. Florida Keys fishermen have been exemplary in initiating regulations for their fishery and monitoring fluctuations in the variety of species they harvest. Concerned fishermen of the Keys continue to work with the FWC to suggest rule changes to ensure sustainability of the marine life fishery.

Ships, Boats and Groundings

Vessel groundings in the Florida Keys occur regularly, and each impacts the benthic environment. The significance of these groundings, and associated restoration alternatives, was detailed in the Florida chapter of the *State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005* (Andrews et al., 2005). In the Florida Keys, the number of reported vessel groundings from years 2002 to 2006 decreased annually (721, 655, 433, 424, and 301 respectively), but it is not possible to determine if this trend is a result of fewer boaters using the resource because of higher fuel costs, increased boater awareness of the sensitivity of the environment, or a decreased willingness to call for assistance if boaters run aground. Generally, there has been no proportional shift in impact to different habitat types with approximately 14% of groundings in coral habitat, an estimated 85% in seagrass and about 1% in hardbottom.

Marine Debris

Traps and "Casitas"

During the 2005 hurricane season, the Keys were subjected to several major storms which mobilized and damaged commercial lobster and stone crab traps, making it practically impossible for fishermen to locate and retrieve their fishing gear. Florida state law (Chapter 68B-55 FAC), which normally prohibits removal of commercial traps by anyone other than their owner or law enforcement officers, threatened to hinder removal efforts. Ultimately, the state of Florida partnered with Monroe County to recover more than 45,000 traps from Monroe County waters, at a cost of more than $1.8 million. Marine debris removal also occurs on a smaller scale, as community coastal cleanup events are regularly organized throughout the year. These events help eliminate trap-related debris that has washed onto mangrove islands and beaches.

Casita is a term used to describe a particular type of fishing gear used to attract spiny lobsters elsewhere in the Caribbean. The term is Spanish in origin and translates as "little house." Within the FKNMS, casitas are not considered traditional fishing gear, and thus are subject to regulation via the National Marine Sanctuaries Act (NMSA) and the Florida Keys National Marine Sanctuary and Protection Act (FKNMSPA). As such, it is against FKNMS regulations to place casitas inside FKNMS boundaries, and it is illegal to harvest spiny lobster from any artificial structure throughout the state of Florida. Casita placement (and presumably the associated lobster harvest) is common in the backcountry area north of the Lower Keys, and there is concern among wildlife management agencies that there could be detrimental effects to natural habitat and lobster population dynamics as a result. Additionally, there are concerns in the commercial trap fishing industry that this practice is unfairly shifting fishery allocation away from the legal lobster trap fishers. In July 2007, a cooperative effort between state and federal partners was implemented to target and remove casitas in the Lower Keys. Simultaneously, fisheries biologists from the state of Florida began evaluating the effect of casitas on the ecology of the backcountry area and the lobster fishery in response to a request from FWC Commissioners.

Derelict and Abandoned Vessels

In a typical year, approximately 100 boats are abandoned in the Florida Keys. In addition to this number, the 2004 and 2005 hurricane seasons caused more boats to be moved into sensitive habitats like seagrass beds and mangrove islands. After the 2005 hurricane season, Monroe County initially surveyed 355 vessels aground, but cleanup operations ultimately removed nearly 500 vessels from the water. More information on derelict and abandoned vessel removal programs can be found at http://myfwc.com/boating/DerelictVessels.htm.

Aquatic Invasive Species

Non-native (exotic) fishes have been increasingly documented in Florida coral reef environments. These species have the potential to disrupt natural coral reef communities due to increased predation of natural species, increased competition for available space and potential introduction of diseases. More than 18 species of non-native marine fish have been documented from Miami/Dade, Broward and Palm Beach counties in Southeast Florida (REEF database, 2006). Lionfish (*Pterois volitans* and *P. miles*), which are included in this number, have become well established along the U.S. east coast, Bermuda and the Bahamas (Figure 6.5). The most likely pathway for introduction of these exotic species in Florida waters is aquarium releases (Semmens et al., 2004)

Figure 6.5. Pterois volitans*, one of two species of lionfish from the Pacific, has become established along the U.S. east coast. It was probably imported for use in an aquarium before being released by its owner into the wild. Photo: P. Whitfield.*

Reports of lionfish range from Rhode Island to the Turks and Caicos Islands, but as of December 2006, no sightings had been reported from Biscayne National Park, the Florida Keys or the Dry Tortugas. The northern records of lionfish sightings have been limited to juvenile fish, however the southern range appears to be expanding both spatially and in abundance. Research by NOAA's National Center for Coastal Ocean Science, Center for Coastal Fisheries and Habitat Research shows that the thermal tolerance of *P. volitans/miles* (11°C minimum) appears to preclude their adult establishment north of North Carolina (Kimball et al., 2004)). However, the increasing abundance and distribution of lionfish in the South Atlantic Bight, Bermuda, Florida and the Bahamas provides strong evidence suggesting lionfish are the first marine fish species to successfully establish a breeding population in the tropical western Atlantic. The venomous nature of lionfish, combined with their voracious feeding habits, unique reproduction and few predators, indicate successful invasive abilities. Sightings of non-native marine fish are being tracked through the REEF Volunteer Fish Survey Project in partnership with federal and state agencies in the hope of preventing additional successful invasions in Florida's marine waters.

Security Training Activities

The 2004 closing of the Navy base in Vieques, Puerto Rico, has not resulted in the anticipated increase in military activities that threaten the coral reef ecosystems of the Florida Keys, but the U.S. Navy is increasing its readiness by improving housing, dockage and aircraft facilities in the Key West area. Plans for grading along the runways of Naval Air Station Key West are being developed that will improve safety conditions there. This construction will affect mangrove and marsh systems, but will not directly affect nearby seagrass and coral resources. In general, security training activities of the U.S. Navy and U.S. Coast Guard are not recognized as a major threat to coral reef ecosystems in Florida. Although these activities can change in response to threats to national security or the need to maintain readiness (e.g., illegal immigration from Caribbean nations), military operations usually undergo review and revision to minimize environmental impacts.

Offshore Oil and Gas Exploration

There is currently no oil or gas drilling occurring in state waters. Florida law prohibits future leasing or drilling of the seabed within the state's Territorial Sea for purposes of oil and gas exploration and development. Holders of any offshore drilling leases that were granted by the state prior to the enactment of the current law must obtain permits under state environmental laws and regulations prior to conducting any drilling activities. No leases exist in Florida areas where coral reef tracts are located.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Historical Ecology of the Florida Keys

Like reef communities worldwide, the Florida Keys have been degraded by overfishing and habitat loss. The roots of degradation pre-date scientific data collection, so historic data are needed to assess long-term change. Historical data sources range from logs kept by early Spanish and British explorers to fishing guides written by recreational fishermen in the 20th century (Figure 6.6). For example, the British cartographer, George Gauld, spent 17 years mapping the Keys in the 1760s and kept a journal where he described the reef as full of fish and wrote that, "there are such quantities of the largest [lobster], that a boat may be loaded with them in a few hours." Gauld also mapped much of the coral reefs in the Florida Keys (Figure 6.7). This kind of historical information can help to develop a baseline for understanding how the natural system functioned before human impacts.

Specific changes documented by historical ecology research include: 1) loss of top predators, such as an extinct species of monk seal which was historically ubiquitous and abundant in coral reef communities; 2) loss of spawning aggregations and reductions in numbers of large fish, such as groupers that have been intensively fished since the 18th century; 3) loss of habitat structure including mangroves, corals and seagrass; 4) reductions in invertebrate populations including conchs, lobsters and urchins; and 5) loss of ecosystem services, such as water filtration by sponges. For example, at its peak, the sponge fishery in the northern Caribbean removed six million pounds of live sponge annually (Figure 6.8). Understanding the degree of change that has occurred over time and how the ecosystem functioned in a more pristine state is essential for management and restoration of Florida's ecologically and economically important reef communities.

A number of coral reef ecosystem monitoring projects are underway in the Florida Keys, making it one of the most intensively studied coral jurisdictions in the U.S. Although no summary table of monitoring activities or map showing the distribution of monitoring locations were prepared for this chapter, many of the important ongoing activities are described below.

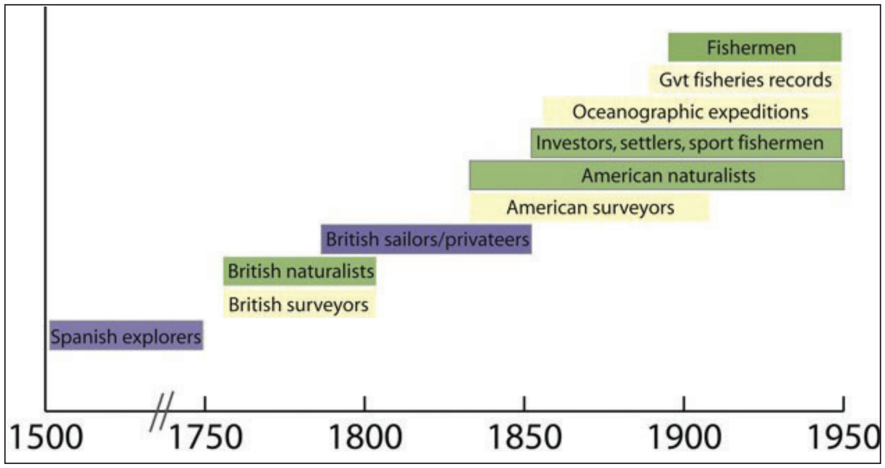

Figure 6.6. Time line for sources of historic resource information about the Florida Keys. Source: L. McClenachan, unpub. data.

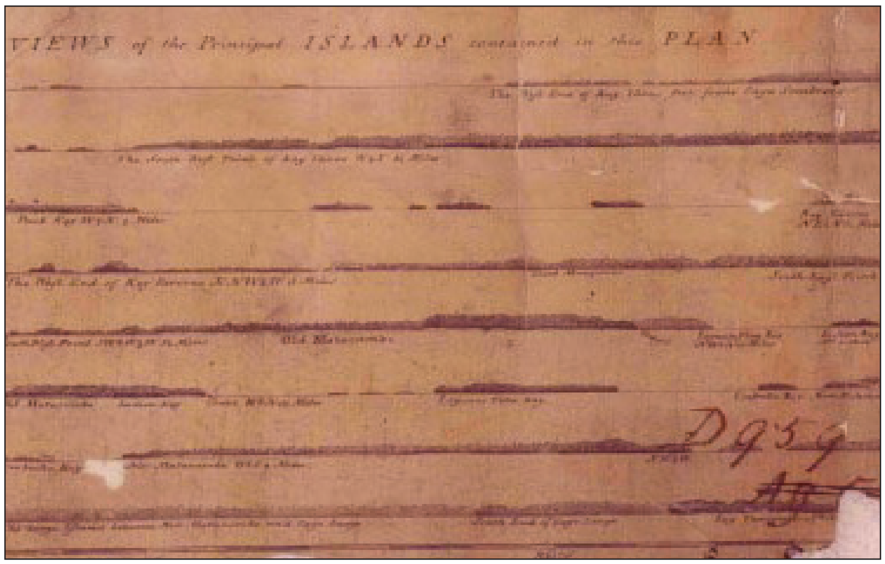

Figure 6.7. Gauld's 1775, "A Plan for the Gulf of Florida". Source: Gauld, 1775.

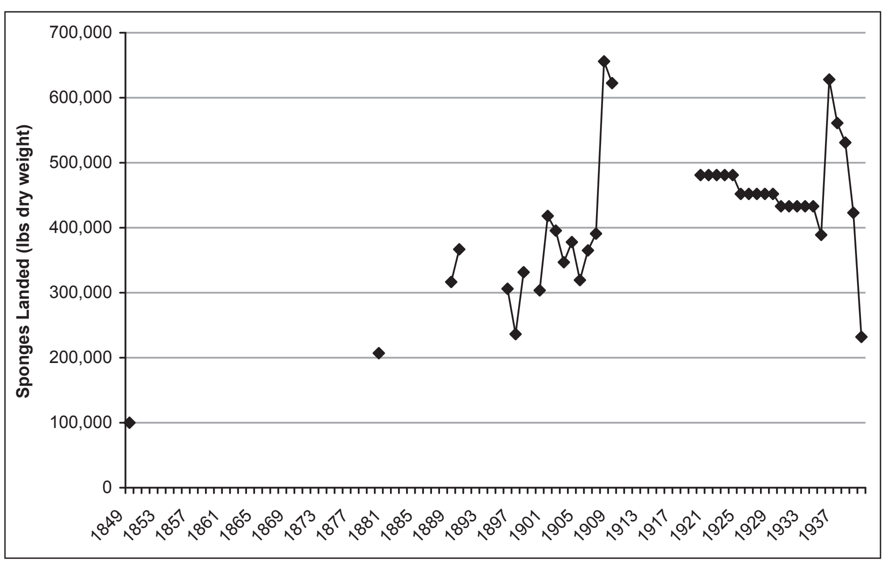

Figure 6.8. Landings of live sponge in Florida, 1850-1940. At its peak, the fishery removed 600,000 lbs annually in dry weight, which is equivalent to approximately 6 million lbs of live sponge. Source: McClenachan, 2008.

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Background and methods for this section are detailed in the Florida chapter of the previous report (Andrews et al., 2005) and the FY2006 *Annual Report of the Water Quality Monitoring Project for the Florida Keys National Marine Sanctuary* (Boyer and Briceño, 2007). Only new information and related discussion are presented in this section.

Several water quality variables were measured *in situ* and from grab samples at 154 fixed stations within the FKNMS boundary from March 1995 to December 2006 (Figure 6.9). Stations were stratified according to water quality characteristics (i.e., physical, chemical and biological variables) using multivariate statistical techniques, an approach that has been very useful in understanding the factors influencing nutrient biogeochemistry in Florida Bay, Biscayne Bay and the Ten Thousand Islands (Boyer and Briceño, 2007). Data from individual sites for the complete period of record were plotted as time series graphs to illustrate any temporal trends that might have occurred. Temporal trends were quantified by simple regression with significance set at $p<0.05$.

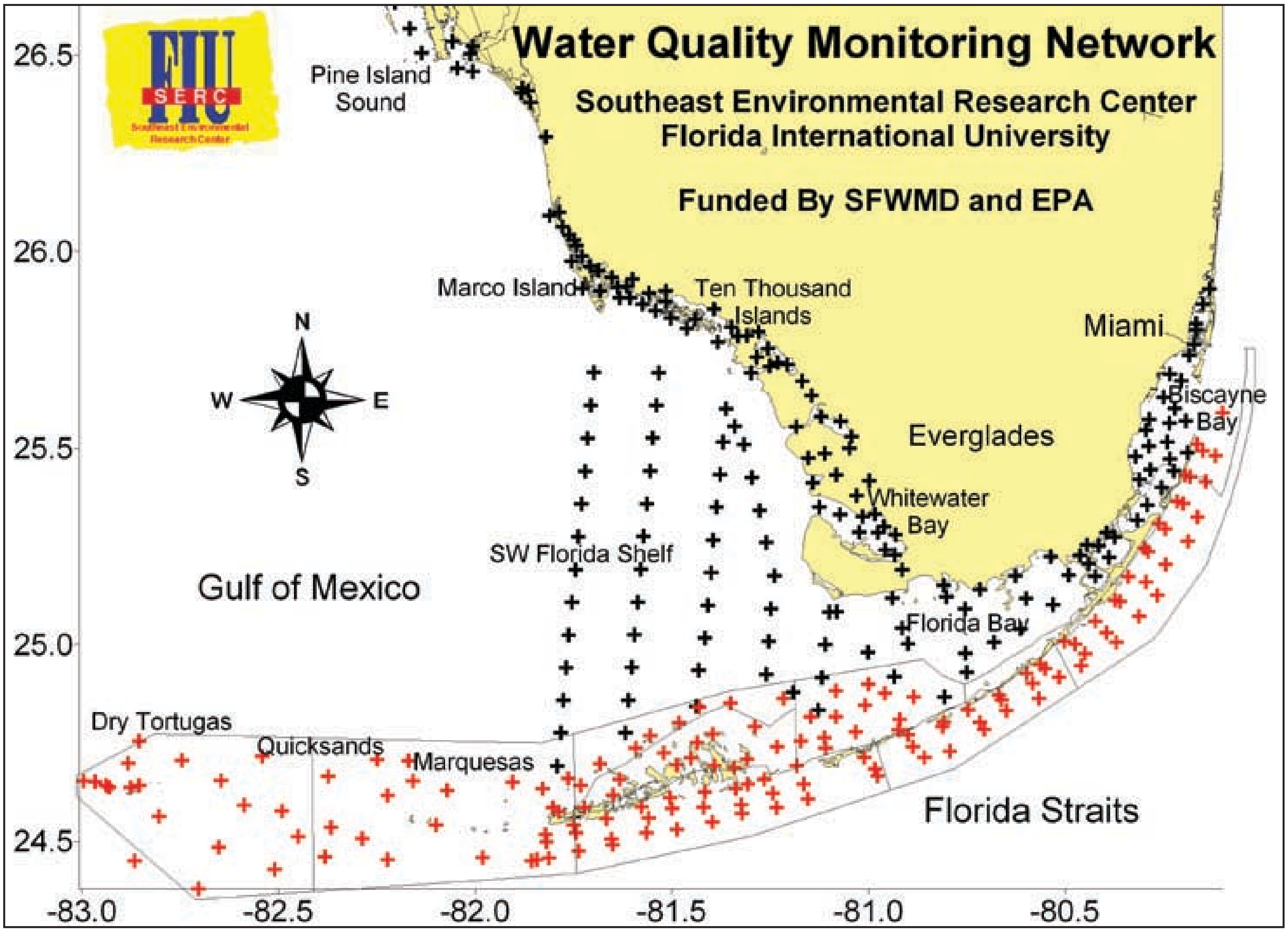

Figure 6.9. The Southeast Environmental Research Center (SERC) Water Quality Monitoring Network showing the distribution of fixed sampling stations, indicated by +, within the FKNMS and Florida Bay, Biscayne Bay, Whitewater Bay, Ten Thousand Islands and Southwest Florida Shelf. SFWMD=South Florida Water Management District. Source: Boyer and Briceño, 2006.

Summary statistics for water quality variables from all 46 sampling events are shown as median, minimum, maximum and number of samples (Table 6.2). Overall, the region was warm and euhaline with a median temperature of 27.1°C and salinity of 36.2; oxygen saturation of the water column (DO_{sat}) was relatively high at 88.5%. On this coarse scale, Sanctuary waters exhibited very good water quality with median nitrate (NO_3^-), ammonium (NH_4^+), and total phosphorus (TP) concentrations of 0.09, 0.29, and 0.19 µM, respectively. Ammonium was the dominant dissolved inorganic nitrogen (DIN) species in almost all of the samples (about 70%). However, DIN comprised a small fraction (4%) of the total nitrogen (TN) pool with total organic nitrogen (TON) making up the bulk (median 11.2 µM). Soluable reactive phosphorus (SRP) concentrations were very low (median 0.02 µM) and comprised only 6% of the TP pool. Chlorophyll a (CHLA) concentrations were also very low overall, 0.23 µg l^{-1}, but ranged from 0.01 to 15.2 µg l^{-1}. Total organic carbon (TOC) was 178.0; a value higher than open ocean levels but consistent with coastal areas. Median turbidity was low (0.63 nephelometric turbidity units or NTU) as reflected in a low light extinction coefficient or Kd value of 0.204 m^{-1}. This resulted in a median photic depth (to 1% incident photosynthetically active radiation or PAR) of approximately 22 m. Molar ratios of nitrogen (N) to phosphorus (P) suggested a general P limitation of the water column (median TN:TP=61.6) but this must be tempered by the fact that much of the TN is not bioavailable.

Several important results have been realized from this monitoring project. The first is the documentation of elevated DIN in the nearshore zone of the Florida Keys (Figure 6.10). This result was evident from our first sampling event in 1995 and continues to be a characteristic of the ecosystem. Interestingly, this gradient was not observed in a comparison transect from the Tortugas. This type of distribution implies an inshore source which is diluted by low nutrient Atlantic Ocean waters. Presence of a similar gradient in TOC and decreased variability in salinity from land to reef also support this concept. There were no trends in either TP or CHLA with distance from land.

Another observation is that the backcountry exhibits elevated levels of DIN, TOC, turbidity, TP and CHLA (Figure 6.11). These distributions are driven by the southwest Florida shelf waters moving through this area (median DIN=0.7 μM, TOC=298 μM, Turbidity=6.4 NTU, TP=0.48 μM, and CHLA=1.6 μg l^{-1}). In addition to south west Florida Shelf influence, elevated NO_3^- is a regular feature of backcountry waters, where some of the highest concentrations are observed in non-populated areas and is probably the result of the benthic flux of nutrients in this very shallow water column.

The third result is that TP concentrations drive phytoplankton biomass (Figure 6.12). Highest CHLA concentrations are seen on the southwest Florida shelf with a strong gradient towards the Marquesas and Tortugas. This is due to higher TP concentrations as a result of southward advection of Gulf of Mexico waters along the coast with entrainment of coastal rivers and runoff.

Finally, trends in water quality showed most variables to be relatively consistent from year to year, with some showing seasonal excursions. Overall, there were statistically significant decreases in DIN, TON (except for increases in Tortugas), TP, TOC and DO throughout the region (Figure 6.13). This is contrary to some of the trend analyses reported in previous years.

Large changes have occurred in FKNMS water quality over time, and some sustained monotonic trends have been observed (Figure 6.13). However, trend analysis is limited to the window of observation; trends may change or even reverse, with additional data collection. This brings up another important point; 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

Table 6.2. Values and sample stations (n) for water quality variables measured in the FKNMS, March 1995 and December 2006. Source: Boyer and Briceño, 2006.

VARIABLE	DEPTH	MEDIAN	MIN	MAX	n
Nitrate (μM)	Surface	0.09	0.00	5.90	6385
	Bottom	0.08	0.00	5.01	3884
Nitrite (μM)	Surface	0.04	0.00	0.71	6394
	Bottom	0.04	0.00	1.73	3891
Ammonium (μM)	Surface	0.29	0.00	10.32	6391
	Bottom	0.25	0.00	3.88	3886
Total Nitrogen (μM)	Surface	11.76	0.73	213.21	6387
	Bottom	9.84	0.88	153.75	3857
Total Organic Nitrogen (μM)	Surface	11.19	0.00	212.89	6363
	Bottom	9.31	0.00	153.43	3830
Total Phosphorus (μM)	Surface	0.19	0.00	1.78	6396
	Bottom	0.17	0.00	1.50	3871
Soluble Reactive Phosphorus (μM)	Surface	0.02	0.00	0.56	6379
	Bottom	0.02	0.00	0.39	3879
Alkaline Phosphatase Activity (μM h^{-1})	Surface	0.06	0.00	5.62	6230
	Bottom	0.05	0.00	0.50	3724
Chlorophyll a (μg l^{-1})	Surface	0.23	0.00	15.24	6395
Total Organic Carbon (μM)	Surface	178.01	18.38	1653.5	6388
	Bottom	151.13	0.00	2135.8	3867
Silicate (μM)	Surface	0.64	0.00	127.11	6089
	Bottom	0.42	0.00	30.20	3692
Turbidity (NTU)	Surface	0.63	0.00	37.00	6350
	Bottom	0.50	0.00	16.90	3907
Salinity (ppt)	Surface	36.2	26.7	40.9	6306
	Bottom	36.2	27.7	40.9	6275
Temperature (°C)	Surface	27.1	15.1	39.6	6313
	Bottom	26.7	15.1	36.8	6282
Dissolved Oxygen (mg l^{-1})	Surface	5.9	0.1	14.5	6278
	Bottom	6.0	1.4	13.9	6229
Light Attenuation Coefficient (m^{-1})		0.204	0.000	4.084	4363
Dissolved Oxygen Saturation (%)	Surface	88.5	1.2	226.2	6277
	Bottom	88.7	19.3	207.0	6227
Water Column Stratification (kg m^{-3})		0.01	-4.42	6.64	6256

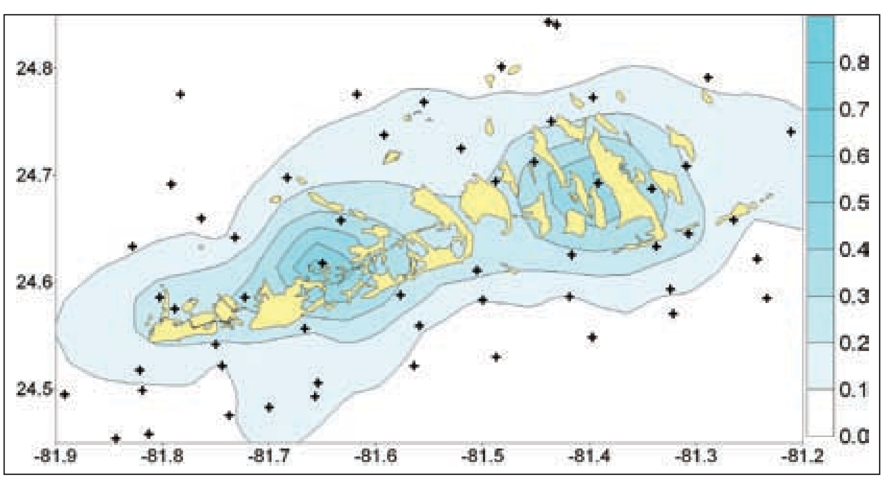

Figure 6.10. Median nitrate concentrations (μM) in the Backcountry for the period 1995 to 2005. Source: Boyer and Briceño, 2006.

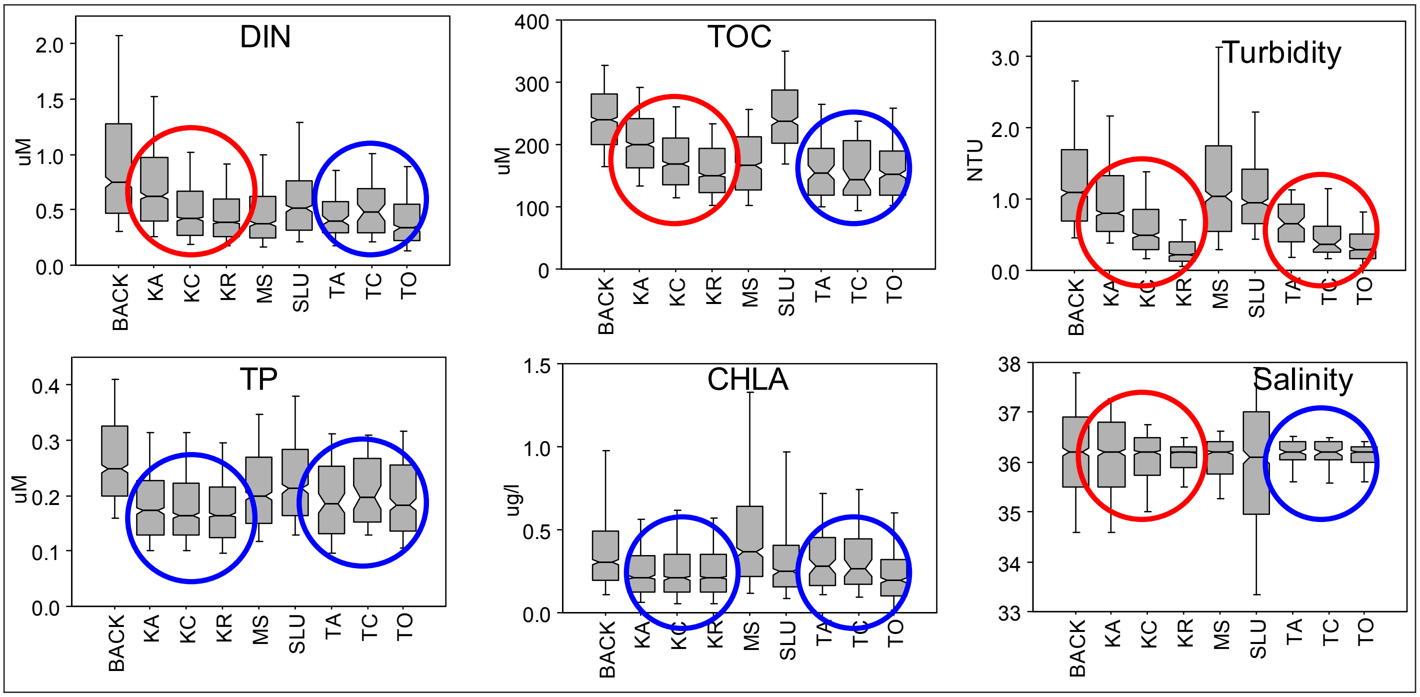

Figure 6.11. Nutrient concentration gradients from alongshore to offshore in Keys reef tract and Tortugas. Red circles denote significant gradient. Box plot shows data distribution and median (notch) of Keys Alongshore (KA), Hawk Channel (KC), and Reef Tract (KR) as well as Tortugas Alongshore (TA), Channel (TC) and Offshore (TO). Source: Boyer and Briceño, 2006.

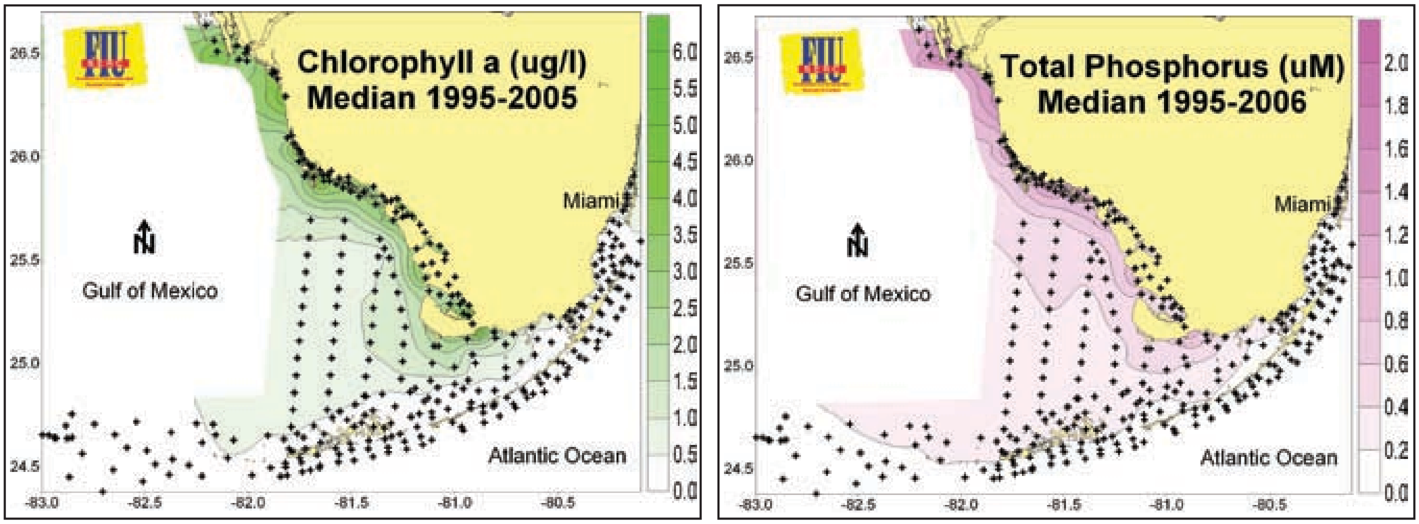

Figure 6.12. Distribution of median concentrations of CHLa (left panel) and TP (right panel) in Florida's coastal waters for the period 1995 to 2005. Sampling stations are indicated with a plus (+) symbol. Source: Boyer and Briceño, 2006.

coastal and estuarine ecosystems driven by similar hydrological and climatological forcings. It is clear that trends observed inside the FKNMS are influenced by regional conditions outside Sanctuary boundaries.

The large scale of this monitoring program has allowed a holistic view of broad physical/chemical/biological interactions occurring over the South Florida region. Much information has been gained by inference from this type of data collection program; major nutrient sources have be confirmed, relative differences in geographical determinants of water quality have been demonstrated and large-scale transport via circulation pathways has been elucidated. In addition, this program demonstrates the importance of looking "outside the box" for questions asked within. 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. Downloadable contour maps, time series graphs and interpretive reports from the Southeast Environmental Research Center's Water Quality Monitoring Network (which includes Florida Bay, Whitewater Bay, Biscayne Bay, Ten Thousand Islands and Southwest Florida Shelf) are available at http://serc.fiu.edu/wqmnetwork
.

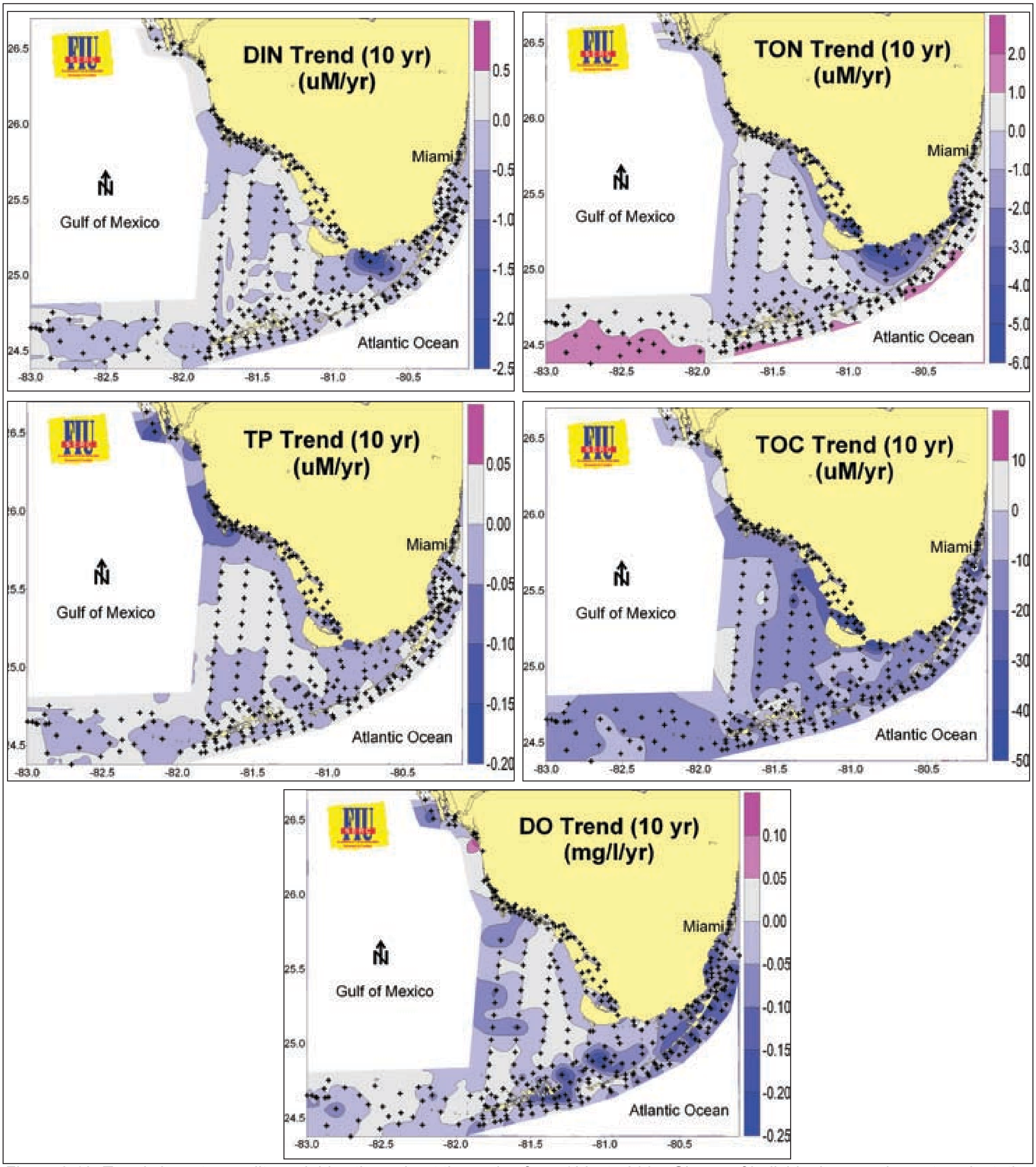

Figure 6.13. Trends in water quality variables throughout the region from 1995 to 2005. Slopes of individual regressions at each station are plotted. Significant decreasing trends are shown in blue while increasing trends are in pink. Sampling stations are indicated with a plus (+) symbol. Source: Boyer and Briceño, 2006.

BENTHIC HABITATS

Coral Reef Evaluation and Monitoring Project (CREMP)
The Florida Fish and Wildlife Research Institute collects annual data on the status of coral habitats in the Florida reef tract through the CREMP. In 1996, data collection began at 40 sites in the Florida Keys. The project was expanded in 1999 to include three sites in the Dry Tortugas. In 2003, 10 additional sites were selected at reefs along Florida's southeast coast and have been monitored annually under the Southeast Florida CREMP (SECREMP) project; the results of the SECREMP work are reported in the Southeast Florida chapter of this report.

CREMP sites encompass four reef habitat categories: hardbottom, patch reef, and offshore deep and shallow reefs. Sites are comprised of two to four permanent stations. Data collection at each station includes an inventory of stony coral species, video transects to assess percent cover of stony coral species and selected benthic functional groups (calculated from images extracted from video), a qualitative assessment of disease and bleaching and a bioeroding sponge survey. Details on sampling design, field methods and data processing and analyses are available at http://ocean.floridamarine.org. Previous reports have documented trends from the project initiation until 2002 (Andrews et al., 2005). This summary will focus on changes observed in coral communities between 2002 and 2005.

Stony coral species richness within the CREMP stations showed a general decline across all habitat types between 1996 and 1999 (Figure 6.14). Between 2005 and 2006, the data show a greater decline in species richness at deep offshore and hardbottom sites than at shallow offshore or patch reef sties in the FKNMS. Some of the smaller or less common species have declined in distribution. For example, in 2006, *Favia fragum*, *Mycetophyllia lamarckiana*, *Leptoseris cucullata* and *Eusmilia fastigiata* were observed in approximately half of the stations in which they were recorded in 2005. Overall there has been a net loss in species richness within the FKNMS since the project's inception. Coral cover at reefs that were historically dominated by acroporid species (*Acropora cervicornis* or *A. palmata*) have been largely reduced to rubble from disease and hurricanes. The Dry Tortugas has historically supported some of the largest populations of *A. cervicornis* in Florida, creating large *Acropora*-dominated patch reefs (Davis, 1982). One of the most luxurious of these acroporid reefs was White Shoal patch reef where coral rubble now comprises a large portion of the substrate. *A. cervicornis* populations in the Dry Tortugas have decreased since the beginning of monitoring in 1999.

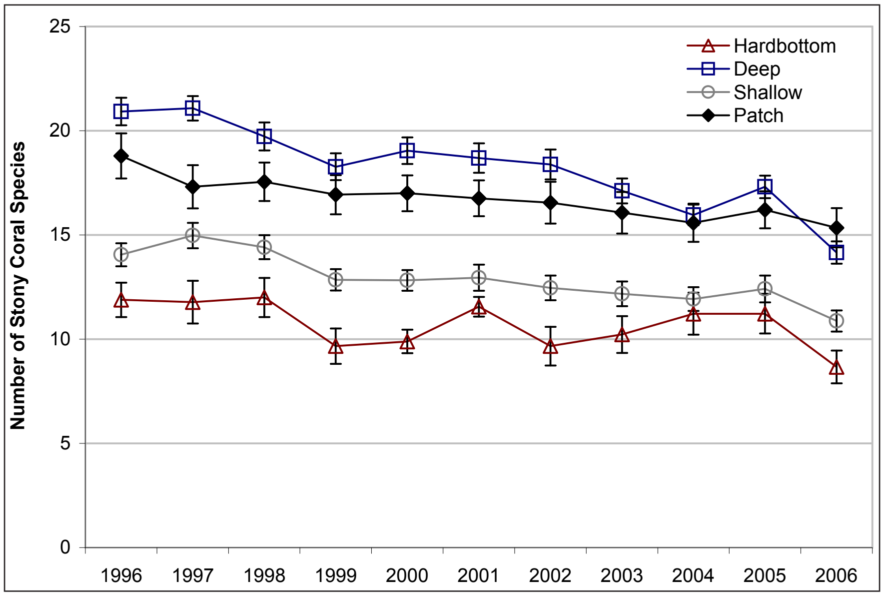

Figure 6.14. Mean number of stony coral species by habitat within the FKNMS. Hardbottom (n=9), deep reefs (n=26), shallow reefs (n=39), patch reefs (n=29). Error bars represent standard error of the mean. Source: CREMP.

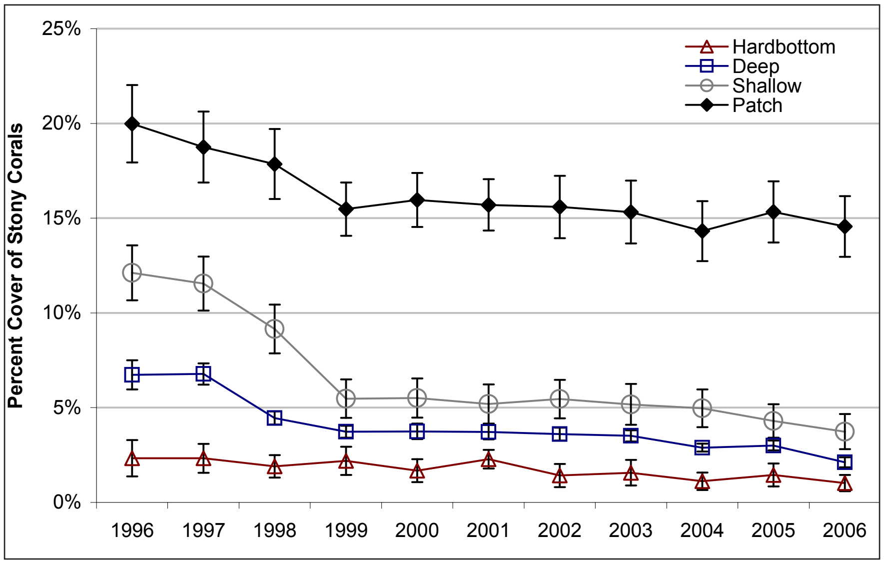

Figure 6.15. Mean percent cover of stony corals by habitat within the FKNMS. Hardbottom (n=9), deep reefs (n=26), shallow reefs (n=39), patch reefs (n=29). Error bars represent standard error of the mean. Source: CREMP.

The relative mean percent cover of stony corals in the FKNMS declined between 1996 and 1999, but was relatively stable from 1999 to 2005 (Figure 6.15). Additionally, between 2005 and 2006 there was a consistent loss of stony coral cover in all regions and habitats sampled in the FKNMS, with the deep offshore reefs showing the greatest decline. This observed decline is likely attributable to loss of cover of the boulder star coral, *Montastraea annularis*. This framework builder has been the dominant species in terms of percent cover and occurrence throughout the sites sampled in the Florida Keys reef system, and has been in decline throughout the duration of the monitoring project.

The hurricanes and tropical storms that affected Florida in 2004-2005 undoubtedly impacted coral habitats. At such a high frequency of occurrence, there has been minimal time for recovery between storms. In 2005, hurricanes Dennis, Katrina, Rita and Wilma each passed over some part of the Florida reef tract. In some locations, structural damage to reefs can be attributed to storm effects; however, storm damage may not always be obvious. Strong waves move sand that can scour or temporarily suffocate corals, causing tissue loss without structural destruction. The summer of 2005 was also marked with periods of unusually calm conditions, which in combination with elevated temperatures (>31°C) caused a severe bleaching event in the Florida Keys. Ironically, the hurricanes also caused the water temperatures to drop below critical bleaching temperatures. The combination of hurricanes and severe bleaching in 2004/2005 is likely primarily responsible for the observed decrease in stony coral species richness and percent cover at the CREMP monitoring sites in 2006. However, the offshore deep sites, which might be expected to be buffered by the effects of hurricanes and bleaching, showed the greatest loss between 2004 and 2006. Since 2002, disease has generally decreased within the CREMP stations within the FKNMS. Diseases can be difficult to distinguish in the field since different pathogens can produce similar symptoms. For CREMP, the white diseases (white plague, white pox, white band) are placed in one category, black band in another, and the remainder in an “Other” category. The number of stations affected with white diseases peaked to more than 80% in 2002, subsided to 35% in 2005, then increased again to 50% in 2006. The number of stations affected with “Other” diseases peaked to 90% in 2001, but declined to 57% by 2006 (Figure 6.16). These data provide information on prevalence, but not on infection rates within the stations. Also, the absence of the disease may indicate the death of colonies that had previously been reported as infected. Despite these caveats, the data indicate that stony coral diseases generally declined from 2002 levels in the Florida Keys.

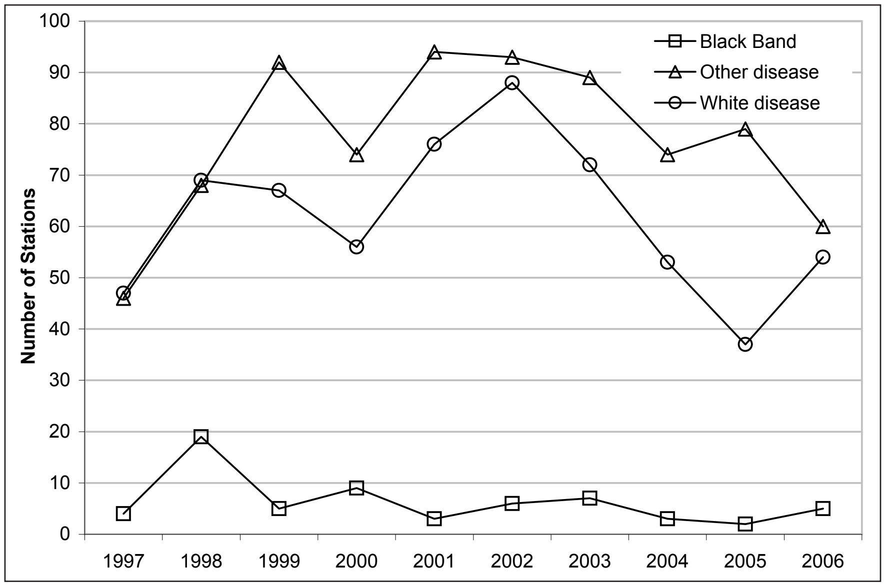

Figure 6.16. Occurrence of Black Band disease, White disease and “Other” disease by station within the Florida Keys National Marine Sanctuary (n=103 stations). Source: CREMP.

Throughout their development, coral reefs have experienced acute (and sometimes catastrophic) events such as anomalous bleaching and hurricanes. Between these events, healthy reefs begin to recover, albeit slowly. However, since monitoring began, the CREMP has not documented significant increases in coral cover at any of the study sites. This lack of recovery could be attributed to chronic environmental changes, from cumulative effects of hurricanes, severe bleaching and disease outbreaks, or a synergy of both chronic and acute impacts. Distance from human habitation has been considered a buffer from the affects of anthropogenic impacts; however, globally there are many examples of reefs that are remote from civilization and are similarly in decline.

Acroporid Species in the Upper Keys

The declines in abundance of two of the principal Caribbean reef-building corals, staghorn (*A. cervicornis*) and elkhorn coral (*A. palmata*), are often-cited examples of the changes in western Atlantic reefs that have occurred over the past several decades (Aronson and Precht, 2001; Gardner et al., 2003). The causes of these declines, which began in the late 1970s, include large-scale factors such as coral bleaching and disease, especially white band disease, as well as smaller scale effects related to storms and predation from corallivorous snails and damselfishes. Both corals have been under consideration for addition to the U.S. Endangered Species List since the early 1990s and were formally added to the list as threatened in 2006 based upon Caribbean-wide population declines and poor recovery.

To help support NOAA’s efforts to ascertain the current status of both Acroporid corals, scientists from the Center for Marine Science, University of North Carolina-Wilmington (UNCW) undertook an intensive assessment of the spatial distribution, colony abundance, size, and condition of staghorn and elkhorn corals in a portion of the FKNMS. During August 1-18, 2006, a total of 107 sites were surveyed in the upper Keys region of the FKNMS from the southern boundary of Biscayne National Park to offshore of Tavernier, a distance of approximately 46 km along the Florida reef tract (Figure 6.17). The 2006 surveys were an outgrowth of previous efforts conducted by UNCW dating back to 1999 to quantify the abundance and condition of coral reef benthos throughout the FKNMS, including the Tortugas region. Previous surveys from southwest of Key West to Biscayne National Park include 80 sites sampled in 1999, 45 sites in 2000, 108 sites in 2001, and 195 sites in 2005; more than 100 sites were also surveyed in the Tortugas region. In 2007, the program was expanded throughout the Florida Keys. More information and project results can be found at http://people.uncw.edu/millers/.

The objectives of the sampling design in the upper Keys region of the FKNMS were to provide information on:

- Habitat-based presence-absence distribution patterns encompassing diverse hard-bottom and coral reef habitat types from 1 to 15 m depth, including a photographic archival record of where both species were found;
- Colony density by site, habitat type and protection level that incorporated all of the existing FKNMS no-take marine reserves in the upper Keys;
- Size distribution of colonies in terms of tissue surface area relative to habitat type;
- Prevalence of colony conditions (normal/healthy, bleaching, disease, predation);
- Population abundance estimates for both species that is habitat and size structured; and
- Density and size of urchins, a continuing effort to monitor recovery of the historically abundant *Diadema antillarum.*

Results and Discussion

A. cervicornis was observed in the general survey area at 19 of the 107 sites (18%) and was recorded within belt transect boundaries at 16 sites. The habitat distribution of this coral was limited to five of the eleven habitat types sampled: mid-channel patch reefs (four of 14 sites, 29%), offshore patch reefs (10 of 23 sites, 43%), shallow (<6 m) low-relief hard-bottom (one of nine sites, 11%), inner line reef tract spur and groove (one of eight sites, 13%), and high-relief spur and groove (three of 17 sites, 18%). A total of 71 staghorn coral colonies were counted within the belt transect boundaries in five of the habitat types. Of these, five colonies (7.0%) were counted from 14 mid-channel patch reefs (13.1% of sampling effort), 47 colonies (66.2%) from 23 offshore patch reefs (21.5% of sampling effort), 10 colonies (14.1%) from nine shallow (<6 m) low-relief hard-bottom (8.4% of sampling effort), four colonies (5.6%) from eight inner line reef tract spur and groove sites (7.5%), and five colonies (7.0%) from 17 high-relief spur and groove sites (15.9%). These data indicate that the distribution patterns of staghorn coral were not proportional to the sampling effort and thus suggest a preferential distribution of this coral. A greater number of colonies than expected (if the habitat distribution is random) were recorded from the two patch reef habitat types, while fewer colonies than expected were recorded from high-relief spur and groove and six of the other habitat types where no colonies were recorded. The greatest mean (± 1 SD) site level densities of 0.333 ± 0.667 colonies/m^2 and 0.183 ± 0.240 colonies/m^2 were recorded from two offshore patch reefs, one in the western area of Carysfort/S. Carysfort Sanctuary Preservation Area (site #83), the other on Mosquito Bank (site #26; Figure 6.18). Overall habitat-level densities were greatest on offshore patch reefs (0.034 ± 0.079 colonies/m^2).

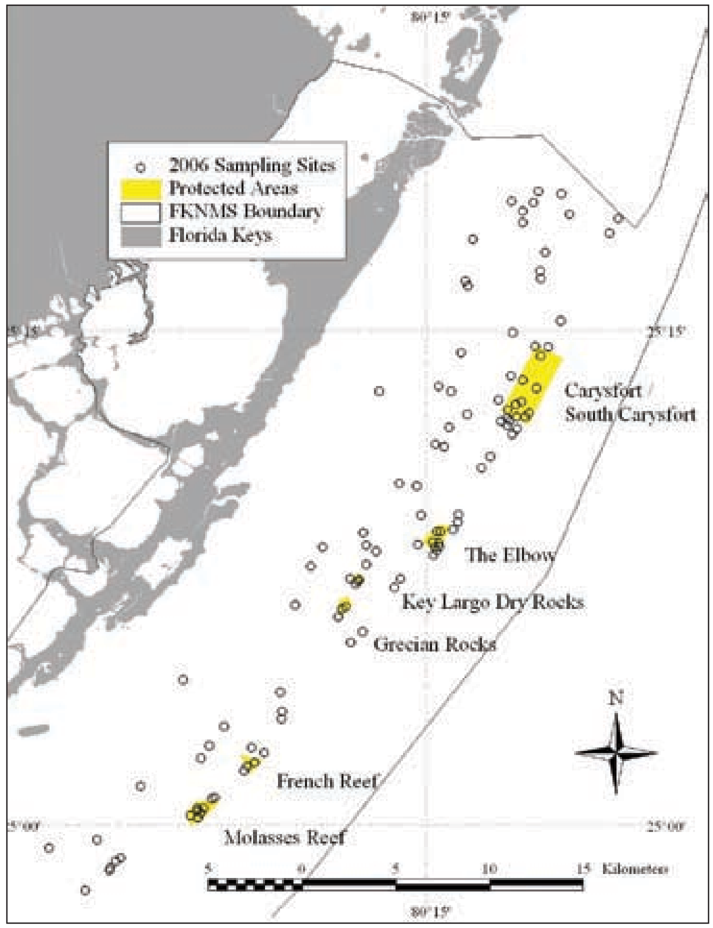

Figure 6.17. In 2006, surveys for Acroporid corals were conducted at 107 sites in the northern FKNMS. Source: Miller et al., 2006b.

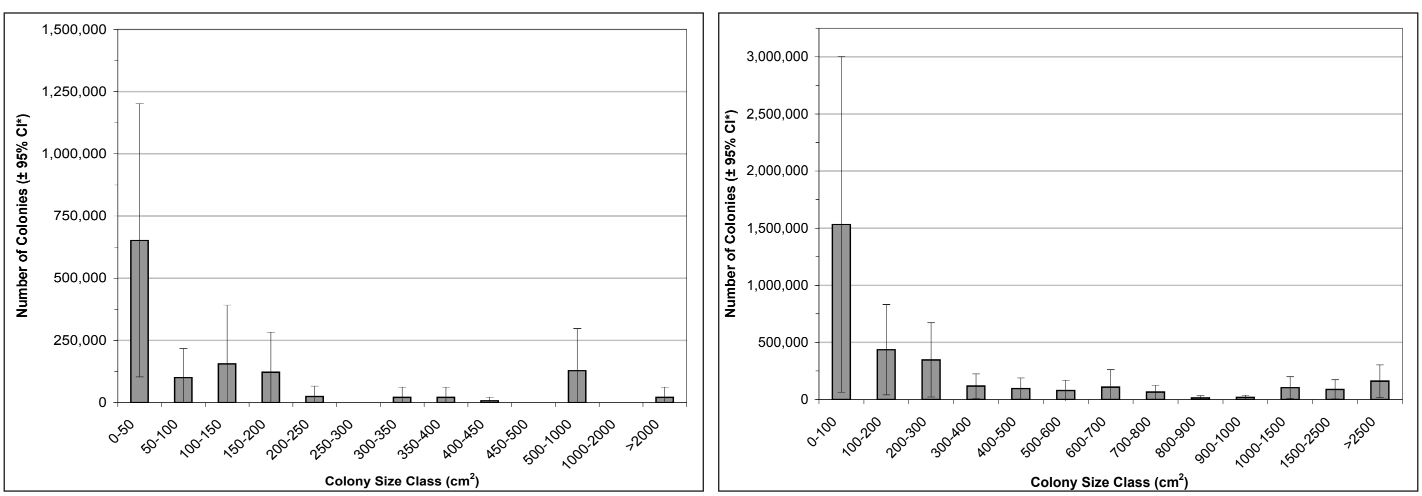

Figure 6.18. Mean colony density of Acropora cervicornis *(left) and* A. palmata *abundance by size class (right) in the upper Florida Keys during 2006, as determined from surveys of four 15-m x 1-m transects per site at 107 sites from northern Key Largo to Tavernier, Florida. Error bars represent one standard error. Colonies were considered to be continuous patches of live tissue. Source: Miller et al., 2006b.*

No staghorn coral thickets larger than approximately 0.5 m in diameter were observed at any location, and most sites with living staghorn coral colonies consisted of mostly small branches. Colony size (live tissue surface area) ranged from 7.4 cm^2 to 127.5 cm^2 and was largest on mid-channel patch reefs and inner line reef tract spur and groove. Nearly 90% of the sampled colonies were less than 100 cm^2 in surface area. Of the staghorn colonies measured, only one colony from the 77 assessed (1.4%) at all sites had obvious signs of damselfish predation. No incidences of white band, white pox or lesions were recorded for staghorn coral during the surveys.

A. palmata was observed at 18 of the 107 sites (17%) and was recorded within belt transect boundaries at 15 sites. The habitat distribution of this coral was limited to four of the eleven habitat types sampled: offshore patch reefs (two of 23 sites, 9%), shallow (<6 m) low-relief hard-bottom (one of nine sites, 11%), inner line reef tract spur and groove (six of eight sites, 75%), and high-relief spur and groove (nine of 17 sites, 53%). A total of 388 elkhorn coral colonies were counted within the belt transect boundaries in four of the 11 habitat types sampled. Of these, 51 colonies (13.0%) were counted from among 23 offshore patch reefs (21.5% of sampling effort), 15 colonies (3.9%) from nine shallow (<6 m) low-relief hard-bottom (8.4% of sampling effort), 100 colonies (25.8%) from eight inner line reef tract spur and groove sites (7.5%) and 222 colonies (57.2%) from 17 high-relief spur and groove sites (15.9%). Clearly the distribution pattern of elkhorn coral with respect to habitat type was not proportional to the sampling effort, indicating a preferential habitat distribution. A greater number of colonies than expected (if the habitat distribution is random) were recorded from inner line reef tract and high-relief spur and groove habitat types. The greatest mean (± 1 SD) site level densities were recorded from high-relief spur and groove reefs at South Carysfort (site #79, 1.967 ± 2.593 colonies/m^2) and Sand Island (site #66, 1.100 ± 1.343 colonies/m^2) and an inner line reef tract site at Horseshoe Reef (site #241, 0.933 ± 1.652 colonies/m^2). Overall habitat-level densities were greatest on high-relief spur and groove and inner line reef tract habitat types.

Elkhorn coral colony sizes showed a significantly greater range compared to its congener, and several sites with large (>0.5 m diameter) colonies were recorded. Colony sizes (live tissue surface area) ranged from 46.3 cm^2 to over 2,000 cm^2 and were greatest on high-relief spur and groove and inner line reef tract habitats. Of the 387 colonies measured, 46% were smaller than 100 cm^2 in surface area, while about 16% were greater than 500 cm^2 in surface area. While most colonies were less than 100 cm^2 in tissue surface area, larger colonies were also relatively common.

Of the elkhorn colonies measured, the most obvious impacts to live tissue were predation by snails (*Coralliophila abbreviata*) and damselfishes (family Pomacentridae). Lobster trap rope was found entangled in thickets of live colonies at South Carysfort Reef, but in general there was an absence of visible diseases such as white band and white pox. Of the 388 colonies assessed for disease and predation, none were found with any visible symptoms of white band, white pox or tissue necrosis. For all sites and habitats combined, 13 colonies (3.4%) were impacted by snail predation and 11 colonies (2.8%) had visible lesions from damselfish predation.

Demographic Monitoring Of Acropora Palmata *In The Upper Keys*

There are many monitoring studies presently in place to assess the general status and trends of Caribbean coral reefs. *A. palmata* is often poorly represented in these studies since its natural distribution is along the reef crest and many studies focus survey efforts on fore reef areas. Furthermore, these studies typically survey randomly placed transects which are not well suited to capture information on *A. palmata's* presently sparse and highly patchy distribution. As a result, very small numbers of *A. palmata* colonies end up in the being counted in general reef monitoring studies. While this accurately depicts the present densities of *Acropora*, it yields very little information on the condition and fate of these remaining colonies. A targeted demographic (i.e., colony-based) monitoring approach (Williams et al., 2006) was used to track the performance of randomly selected "individual" colonies over time. In this way, the relative importance of the many sources of mortality for populations of *A. palmata* can be determined because combining the prevalence of a particular threat with the subsequent fate of affected colonies (or lethality) will show the ecological importance of the various threats. Thus, randomly selected colonies are tagged, measured (two diameters and height), photographed, and scored based on the estimated percent of live tissue and the presence and severity of a particular list of "threat" conditions on a regular basis. The "amount of live coral" is estimated by a Live Area Index (LAI) = [mean of 3 colony dimensions]^2 x [% of colony with live tissue]) for each colony and summed for the colonies at each site. A total of 192 colonies in 15 plots (7 m radius) were tagged at five reefs in the upper keys (between Carysfort and Molasses reefs) in early 2004. Surveys were conducted quarterly through 2006.

Results and Discussion

Overall, *A. palmata* populations in the upper Florida Keys display a declining trajectory between 2004 and 2006 with particularly acute losses observed during summer and fall of 2005 (overall approximately 50% loss; Williams and Miller, 2006; Figure 6.19). These losses resulted from hurricane effects and subsequent disease impacts. It should be noted that this observed decline is based on an already critically depressed baseline value measured in 2004 (Miller, 2002).

Slight recovery has been observed between fall 2005 and summer 2006, though 37 colonies have suffered complete mortality and 31 were physically removed by the hurricanes. Although the fragments generated from colonies that were substantially broken or completely removed could potentially yield new colonies (asexual recruits), approximately 70% of the 369 fragments counted after the passage of Hurricane Dennis were dead or loosing tissue rapidly. Recovery of live *A. palmata* has resulted primarily from re-growth of remnant crusts (Figure 6.20), including the formation of new branches. Less than 5% of the fragments observed in the study plots have successfully reattached and survived to date, and only one recruit that is believed to be of sexual origin has been observed. Thus, total recruitment appears to be low and does not offset the observed losses in the tagged colonies.

Demographic monitoring relies on tracking the performance of individual colonies to document the threats they face and their fate over time. For example, parrotfish bites may be extremely common among a population, but if effects on a colony are minor, they may be relatively unimportant to the viability of the population. Management and conservation resources can be more effectively applied based on an understanding of the relative impacts of threats on populations. Unfortunately, between 2004 and 2006, relatively "unmanageable" threats (hurricanes and disease) have accounted for substantial losses of live coral tissue including entire colony mortality. This emphasizes the imperative for management and conservation resources (i.e., funding) to support immediate research efforts to determine the proximal and ultimate causes of disease impacts and to identify corrective actions to mitigate disease losses for all Caribbean corals, but particularly Caribbean acroporids.

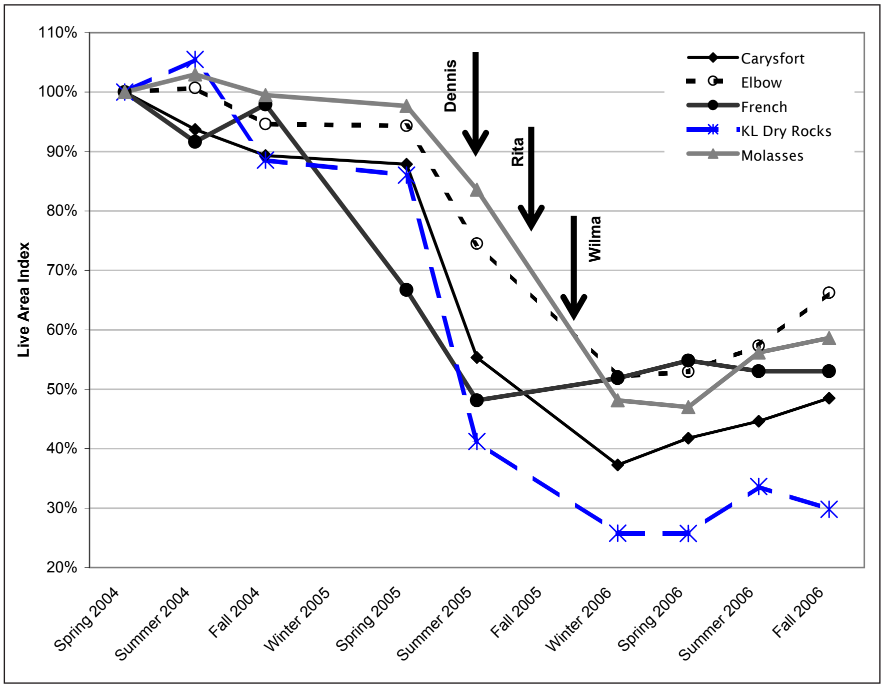

Figure 6.19. Trend in Acropora palmata *LAI between 2004 and 2006 in the upper Florida Keys National Marine Sanctuary. Each line represents mean percent of the original sum of LAI for 10-12 tagged colonies per 7 m radius plot (n=1 to 5 plots per site). A total of 192 colonies were originally tagged. Source: Williams and Miller, 2006.*

ASSOCIATED BIOLOGICAL COMMUNITIES

Native Americans fished for reef fishes on Florida reefs long before the arrival of European settlers (Oppel and Meisel, 1871). Reef fishing accelerated in the 1920s. Following growing public conflicts and sharp declines in catches, monitoring programs at the species level began in the early 1980s (Bohnsack et al., 1994; Bohnsack and Ault, 1996; Harper et al., 2000, Ault et al., 2005a).

Recreational, commercial and "headboat" fisheries currently occur in Florida Keys waters. From a recreational standpoint, fishers include both local residents and visitors (FWC, 2007). Along the reef tract, the most commonly targeted species are members of the snapper-grouper complex, including snappers, groupers, grunts, hogfish and porgies. From a commercial standpoint, fisheries target reef and pelagic fish species, spiny lobster, stone crabs, blue crabs, shrimp and ballyhoo. Headboat fisheries, in which customers pay "by the head" to fish from vessels with a typical capacity of about 10-20 people, predominantly target reef species.

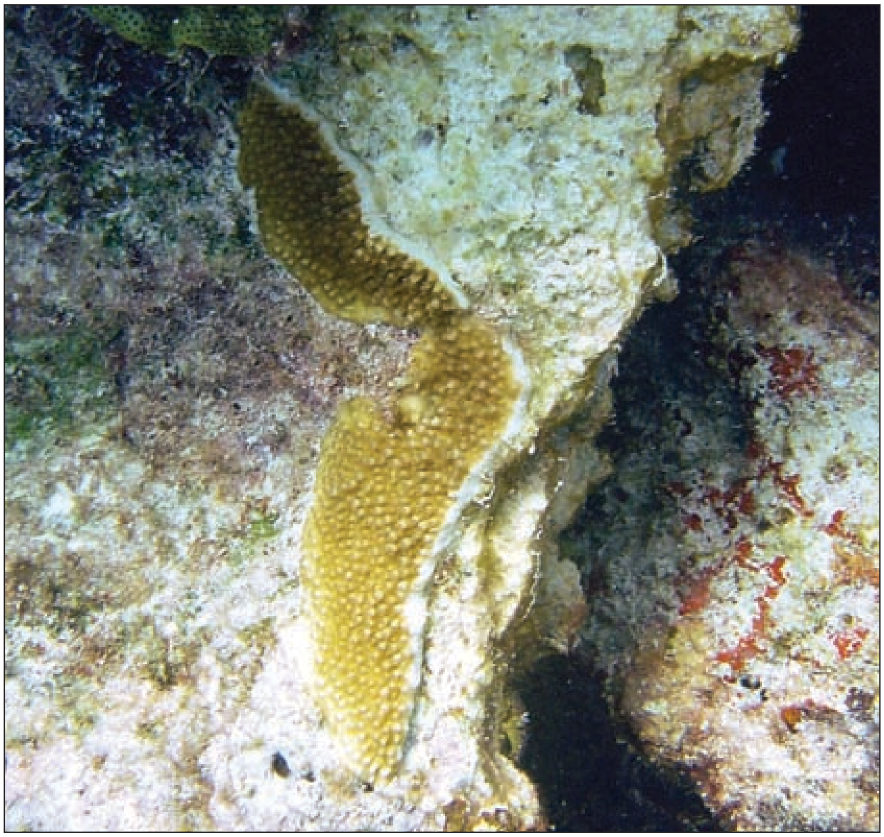

Figure 6.20. Photograph of remnant crust approximately 20 cm long. After a series of hurricane impacts in summer/fall 2005, this was all that remained of a colony that was previously over a meter tall and wide. Photo: D. Williams.

Trends in reef fish landings for the period 1981 to 1992 were reported for the Florida Keys by Bohnsack et al. (1994). Depending on the year, recreational landings comprised between 40 and 66% of total landings. Reef fishes accounted for 58% of total fish landings, 69% of recreational landings and 16% of commercial landings. Commercial landings were dominated by invertebrates (spiny lobster, shrimp and stone crabs), which comprised 63% of total landings.

In a 2005 report to the U.S. Congress, the National Marine Fisheries Service (NMFS) classified 11 species that are landed in the Florida Keys as overfished (i.e., depleted below minimum standards), and 11 as subject to overfishing (i.e., being fished at a rate that would lead to being overfished), with some overlap between the two categories (NMFS, 2005). Included in these totals are reef-associated species such as gag (*Mycteroperca microlepis*), black (*M. bonaci*), red (*Epinephelus morio*), snowy (*E. niveatus*), Warsaw (*E. nigritus*), Goliath (*E. itajara*) and Nassau (*E. striatus*) groupers, speckled hind (*E. drummondhayi*), and red (*Lutjanus campechanus*) and vermilion (*Rhomboplites aurorubens*) snappers. Fisheries for Goliath and Nassau groupers and for queen conch (*Strombus gigas*) were closed in 1985 and remain closed today, although the Goliath grouper stock continues to indicate signs of recovery (Porch et al., 2003 and 2006) to the extent that considerable debate occurs regarding re-opening of that fishery.

Ault et al. (1998) assessed the status of multiple reef fish stocks and determined that 13 of 16 groupers (Epinephinilae), seven of 13 snappers (Lutjanidae), one wrasse (hogfish; Labridae) and two of five grunts (Haemulidae) were overfished according to federal (NMFS) standards (Figure 6.21). They suggested that some stocks appeared to have been chronically overfished since the 1970s, and that the Florida Keys fishery exhibits classic "serial overfishing" in which the largest, most desirable species are depleted by fishing (Ault et al., 1998). Ault et al. (2001) found that the average size of adult black grouper in the upper Keys was about 40% of its 1940 value, and that the spawning stock for this species is now less than 5% of its historical unfished maximum. In subsequent analyses, Ault et al. (2005a and 2005b) determined that, of 34 species within the snapper-grouper complex for which sufficient data were available, 25 were experiencing overfishing.

Partly in response to concerns about fishing pressure, the FKNMS established a series of Sanctuary Preservation Areas (SPAs) in 1997. Comparison of fish and benthic communities within versus outside of SPAs is underway. The FKNMS also created the Tortugas Ecological Reserve (TER) in 2001 to protect coral reef ecosystem services in that area and support sustainable reef fisheries. The TER protects 150 nmi^2 and prohibits all anchoring, fishing and other extractive activities; it was the largest marine reserve in North America when first implemented. Scientists at the University of Miami and NMFS have studied and reported on responses of coral reef fish populations to this reserve. Based on data collected during more than 4,000 research dives, they compared changes in the Dry Tortugas region between 1999 and 2000 before the reserve was established and in 2004, three years after the reserve was established (Ault et al., 2006). As predicted by marine reserve theory, significant regional increases in abundance for several exploited and non-exploited species were detected. Significantly greater abundance of large fish were found in the TER for black grouper (Figure 6.22), red grouper (Figure 6.22) and mutton snapper compared to the baseline period. No significant declines were detected for any exploited species in the reserve, while non-exploited species showed both increases and declines. Abundance of exploited species in fished areas on the Tortugas Bank either declined or did not change. A comparison of black grouper size distributions as a function of management zone is given in Figure 6.23.

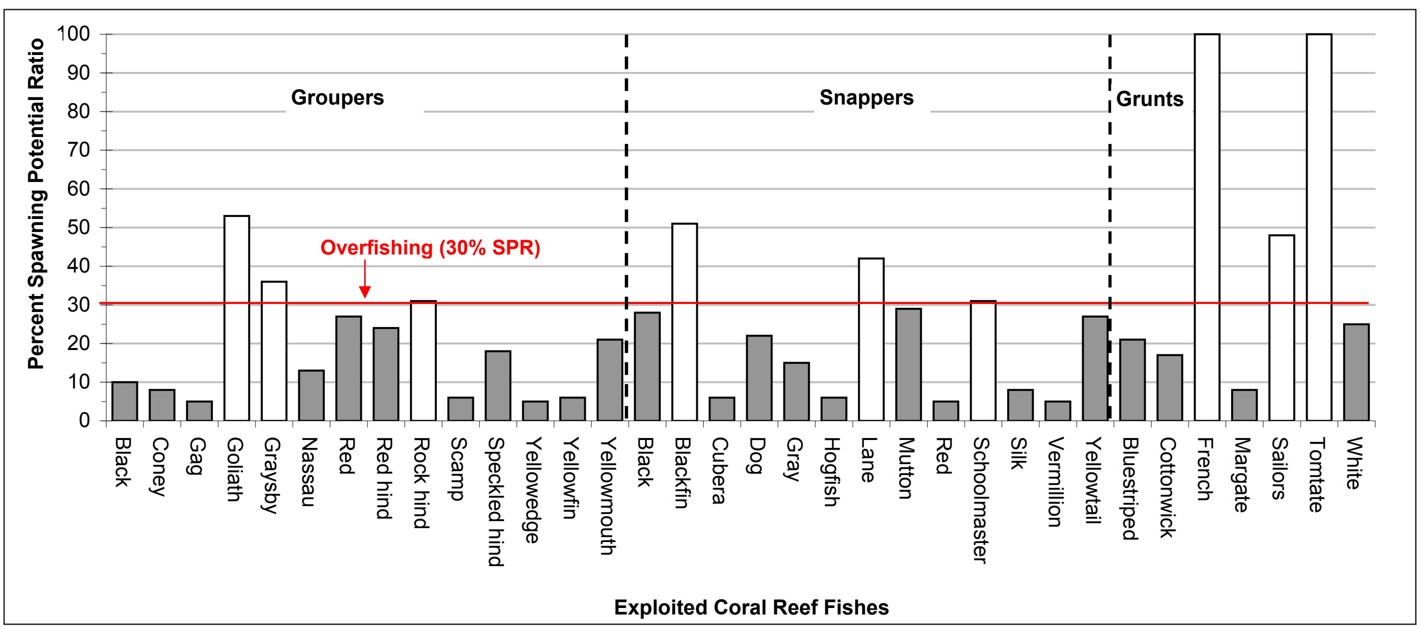

Figure 6.21. Spawning potential ratio (SPR) analysis for 34 exploited species in the snapper-grouper complex from the Florida Keys for period 2000-2002. Dark bars indicate overfished stocks and open bars indicate stocks that are above the 30% SPR standard. Source: redrawn from Ault et al., 2005a.

On January 19, 2007 the National Park Service (NPS) established a 119 km^2 (46 mi^2) Research Natural Area within the DTNP. This area is contiguous to the northern portion of the FKNMS Tortugas Ecological Reserve and effectively expanded the marine reserve network since it also prohibited all anchoring and extraction. Ongoing research and monitoring are planned to ascertain whether patterns observed in protected areas in the Tortugas are due to influences of marine reserves, confounding effects of recent changes in fishing regulations, hurricane disturbances, or random oceanographic and chance recruitment events.

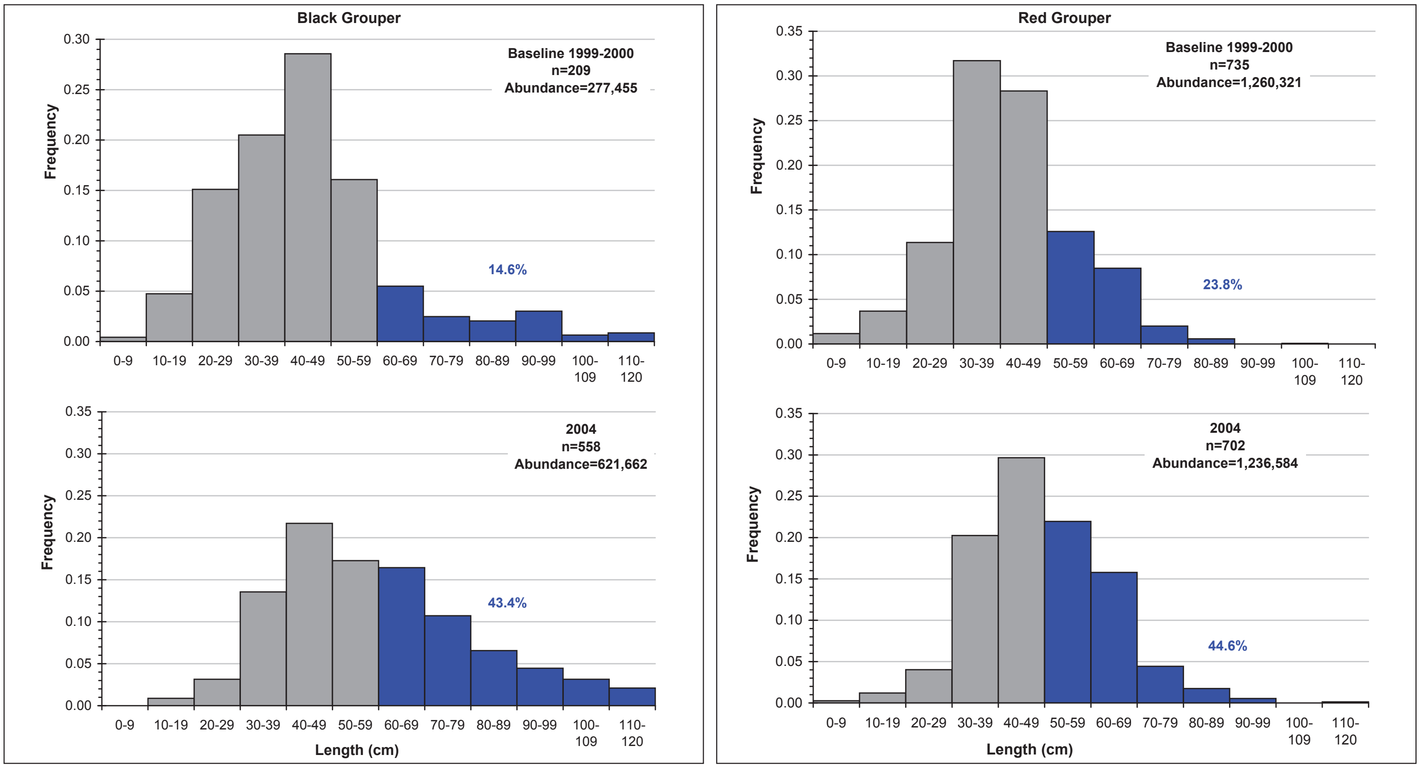

*Figure 6.22. Black grouper (*Mycteroperca bonaci*; left panels) and red grouper (*Epinephelus morio*; right panels) size distributions from the Tortugas region in 1999-2000 (top) and 2004 (bottom), before and after the establishment of the TER in 2001. Blue bars represent size classes larger than the minimum legal minimum size. Percentages show the proportion of the population larger than the legal minimum size of capture. Source: redrawn from Ault et al., 2006.*

FWC Finfish Monitoring

Florida's Fish and Wildlife Conservation Commission (FWC) conducts visual censuses between April and October to monitor finfish populations along the Atlantic margin of the Florida Keys in waters of the FKNMS. The principal goal of the visual census surveys is to evaluate the relative abundance, size structure and habitat utilization of the reef fish species that comprise local, commercial and recreational fisheries in the Florida Keys reef ecosystem. The consistent application of monitoring methods and robust sample sizes permit meaningful statistical analysis of the data collected.

Methods

For the purposes of this study, the sampling universe in the FKNMS was divided into six geographical zones, designated A through F, four of which (A–D) were sampled during the present study (Figure 6.24). A habitat-based, random-stratified site selection procedure, based upon the *Benthic Habitats of the Florida Keys* GIS maps (NOAA, 1998), was used to select 39 sample sites (13 in Zone A, 10 in Zone B, 6 in Zone C and 10 in Zone D) each month. Sampling sites were randomly selected using a one longitudinal by one latitudinal minute grid (approximately 1 nmi^2) system. One mile square grids containing areas defined as "Patch Reefs" and "Platform Margin Reefs" were included in the sampling universe, with further random selection of one of 100 "micro-grids" within each selected sampling grid (Figure 6.24). Within each grid chosen for sampling, a second random selection of one of one hundred 0.1′ x 0.1′ "micro-grids" (approximately 0.01 nmi^2) determined the nominal location within the grid, providing that micro-grid contained reef or patch reef habitat adequate for sampling purposes (Figure 6.24). If this was not the case, a randomization procedure was used to relocate the sample to a nearby micro-grid with the desired habitat.

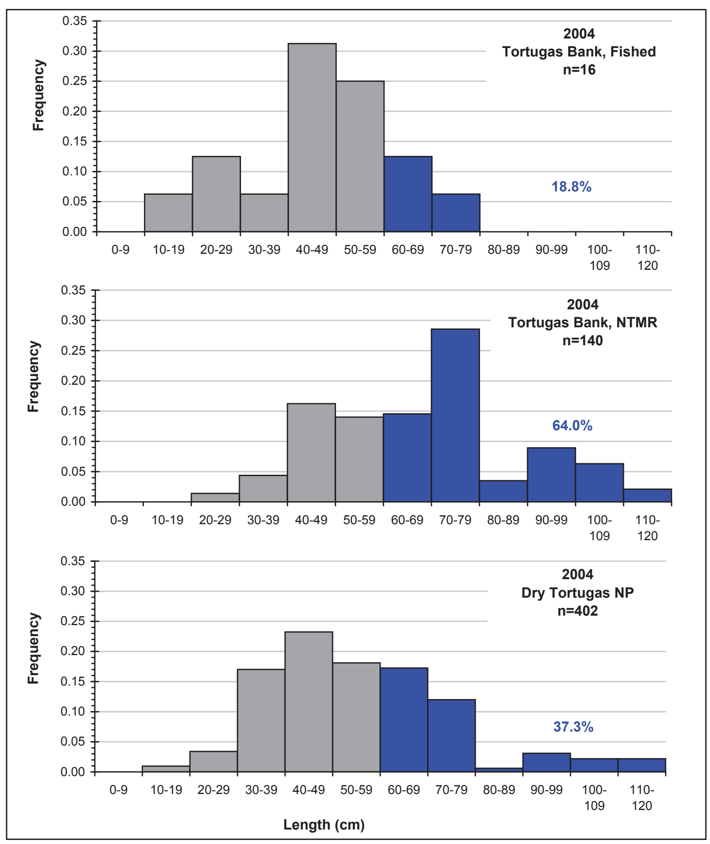

Figure 6.23. Black grouper size distributions in 2004 from fished (top) areas on the Tortugas Bank, unfished (middle) areas in the NTMR and recreational angling areas in the DTNP (bottom). Blue bars indicate size classes larger than minimum legal size; percentages show the proportion of the population larger than legal minimum size. Source: redrawn from Ault et al., 2006.

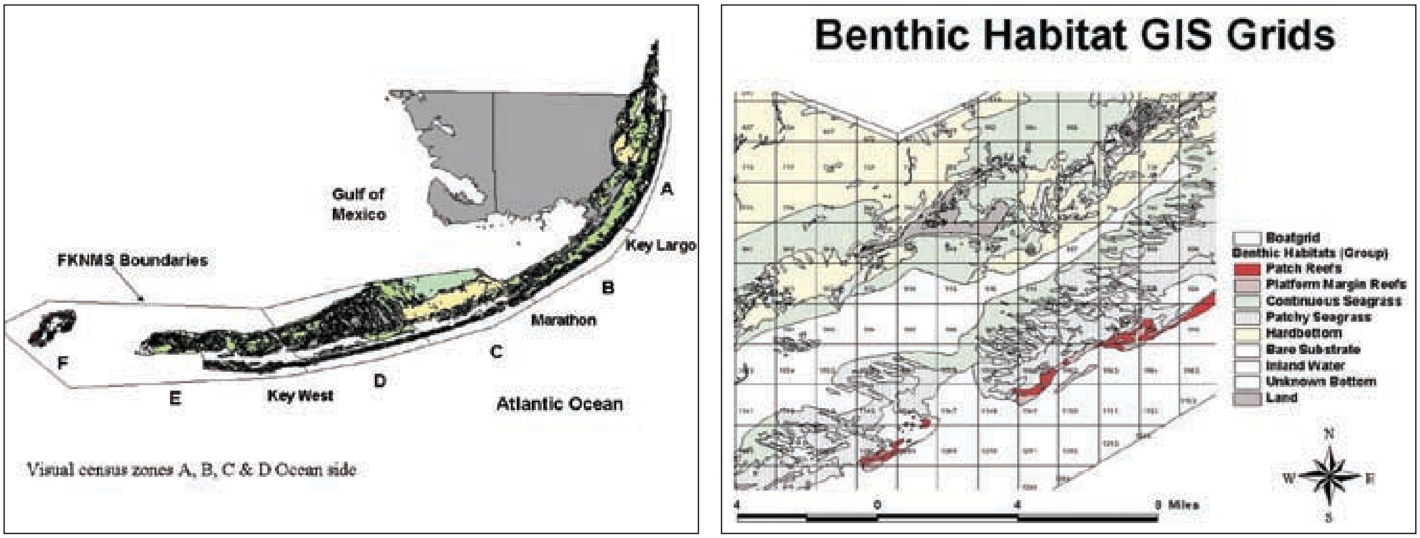

Figure 6.24. Map of Fisheries-Independent Monitoring Program sampling areas divided into four zones (A-D), in the FKNMS (left), representing a habitat-based, random-stratified site selection procedure based upon FDEP and NOAA's (1998) mapping product "Benthic Habitats of the Florida Keys" (right). Source: FWC-FWRI, 2007; FDEP and NOAA, 1998.

In 1999 and 2000, data was collected using both belt transects and point counts. From 2001-2007, only stationary visual point counts were used. In this method, a stationary diver records the number of individuals of each target species that are observed within an imaginary 5 m radius cylinder and assign length intervals to each. Two divers conduct a total of four point counts at each site. During the visual survey, each diver lays out a 25 m tape in a pre-determined direction opposite from the other diver. The tapes are laid as straight as possible within the same habitat type, with at least a 15 m distance between each point count. The first count is conducted at the 10 m mark, and a second count is conducted at 25 m. If suitable habitat is not present at the designated mark then the distance is adjusted accordingly. At each survey point, the diver stops and remains still for two minutes, allowing for a settling period. During this time period, the diver records depth, substrate, habitat type, relief, complexity, percent and type of biotic coverage within the area to be surveyed, which is the cylindrical area extending out 5 m from the center point and from the substrate to the surface. After the settling period, the diver records the time and begins estimating the number of fish in each five-centimeter size class for all the target species present. The diver has three minutes to allow the fish to naturally redistribute themselves and to list the target species present within the survey cylinder. This time period also allows for cryptic species to reveal themselves for counting. The target species include 54 species of commercial and recreational importance that are members of the following families: Haemulidae (13 species); Serranidae (13 species); Lutjanidae (nine species); Chaetodontidae (seven species); Balistidae (three species); Labridae (three species); Phomacanthidae (two species) and Priacanthidae (two species).

Results and Discussion

Overall mean densities (number of fish/100 m^2) observed from point counts ranged from 37 fish/100 m^2 in 2000 to a high of 69 fish/100 m^2 in 2003. Overall mean densities have been increasing since 2001 (Figure 6.25) and were higher in Zone C and lower in zone D. A total of 273,191 animals of the target species were recorded during 6,454 point count surveys between 1999 and 2006 (Table 6.3). 89% of these fish were from the smallest size classes (>5 to 20-25 cm range). Fish in the family Haemulidae strongly dominated the point count observations, accounting for 67.6% of all individuals recorded, with *Haemulon plumieri*, *H. aurolineatum*, *H. sciurus* and *H. flavolineatum*, comprising 58.7% of the total number of haemulids (Table 6.3).

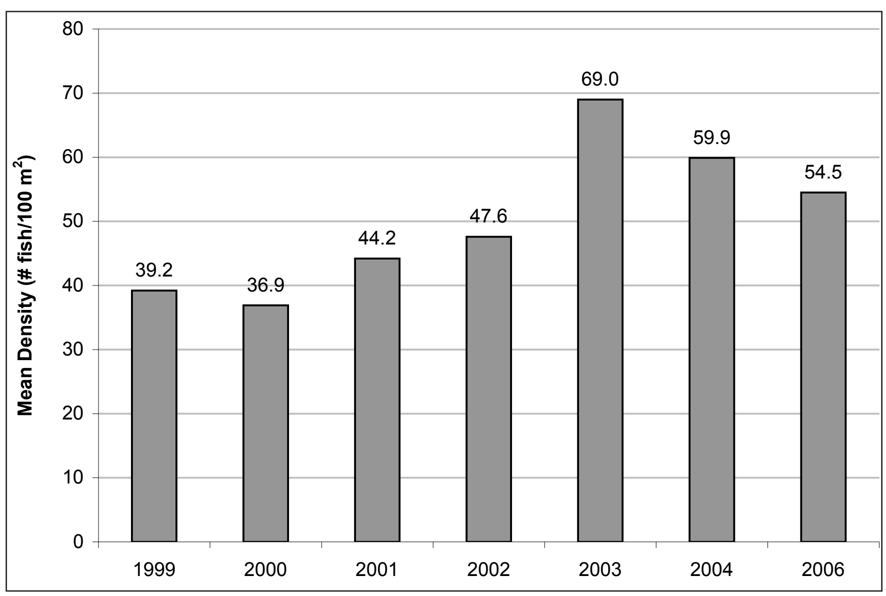

Figure 6.25. Mean fish density by year (2000-2006) as recorded during visual surveys in the Florida Keys. Source: FWC-FWRI, 2007.

Overall length-frequencies observed during point counts have been largely similar between years for most species. Length ranges and size distributions for economically important species such as *Ocyurus chrysurus*, *Lutjanus griseus*, *L. maximus*, *Epinephelus morio* and *Mycteroperca bonaci* have been very consistent through the years sampled. Only a small percentage of groupers and snappers were observed in the larger size classes during the seven years of sampling, and these percentages varied by species and year. For example, observations of large individuals of *E. morio* decreased from 22.8% in 2004 to 16.8% in 2006; sightings of large *M. bonaci*, increased from 15.0% in 2004 to 16.4% in 2006. No legal-size (i.e., fish that can legally be caught and retained) individuals of *M. microlepis* were observed in 2006, compared to 11.1% in 2004. *Ocyurus chrysurus* showed a slight increase in the number of legal-size fish observed with 4.8% at or above the legal limit in 2006 compared to 3.8% in 2004, yet this was still lower than in 2003 (7.4%).

Table 6.3. Catch statistics for the 15 more abundant Reef Fish Species observed during Florida Keys visual sampling, 1999-2006. Percent (%) is the percentage of the total observations represented by that species; percent occurrence (% Occur) is the percentage of samples in which the species was observed; CV is the coefficient of variation. Taxa are ranked in order of decreasing mean density. Source: FWC-FWRI, 2007.

SPECIES	NUMBER		% OCCUR	DENSITY ESTIMATE (ANIMALS/100 m^2)			
	No.	%		Mean	SE	CV	Max
Haemulon plumieri	57,017	20.9	82.4	11.50	0.55	193.82	342.82
Haemulon aurolineatum	52,227	19.1	20.3	10.17	1.16	461.30	925.01
Ocyurus chrysurus	26,162	9.6	65.9	5.75	0.32	224.87	154.49
Haemulon sciurus	28,017	10.3	41.5	5.71	0.44	309.10	291.57
Haemulon flavolineatum	22,879	8.4	41.0	4.57	0.35	310.47	226.00
Haemulon spp.	16,815	6.2	10.1	3.38	0.48	576.75	318.31
Lutjanus griseus	13,241	4.8	35.5	2.95	0.29	403.80	268.23
Lachnolaimus maximus	7,400	2.7	79.3	1.62	0.07	167.30	45.41
Lutjanus apodus	5,441	2.0	19.1	1.21	0.16	547.55	143.88
Anisotremus virginicus	4,697	1.7	47.2	0.96	0.07	285.19	56.34
Pomacanthus arcuatus	3,490	1.3	67.2	0.75	0.03	146.03	13.58
Chaetodon capistratus	3,455	1.3	52.3	0.74	0.03	145.13	7.64
Haemulon melanurum	3,693	1.4	8.5	0.72	0.13	714.10	93.90
Haemulon chrysargyreum	3,502	1.3	4.9	0.70	0.14	788.99	95.49
Pomacanthus arcuatus	3,490	1.3	67.2	0.75	0.03	146.03	13.58
Chaetodon capistratus	3,455	1.3	52.3	0.74	0.03	145.13	7.64
Subtotal	197,964	72.7	--	--	--	--	--
Totals	273,191	100.0	--	56.03	1.99	143.90	1,141.77

MACROINVERTEBRATES

FWC Spiny Lobster Monitoring

The FWC undertook a lobster monitoring program in 1997 to test the hypothesis that no-take zones would sufficiently protect spiny lobster so that their average abundance and size would increase in protected zones compared to similar fished areas. Spiny lobster monitoring in the FKNMS began at the time of reserve establishment.

Methods

From 1997-2001, 13 reserves and similar adjacent fished areas were surveyed during the closed and open fishing seasons. Reserves were comprised of 11 SPAs (mean size 82 ha), one large SPA (515 ha) and one 3,000 ha Ecological Reserve (ER) at Western Sambo. From 2002 through 2005, sampling effort at three sites including the ER was only conducted during the closed fishing season. A full survey of the 13 reserve/fished area pairs was conducted during the closed season of 2006, the tenth year of the reserves. Surveys consisted of 60-minute timed searches for spiny lobsters. More information on data collection methods can be found in Cox and Hunt (2005).

Results and Discussion:

In 1997, mean lobster size was below the legal limit in both reserves and exploited areas. Since protection, mean lobster size in reserves has been larger than legal size, whereas in exploited areas it remained below the legal limit in most years. In all years, legal-sized lobsters with a carapace length ≥76 mm found in SPAs were as large as or larger than those in fished areas (Figure 6.26). In most years, abundance declined in both reserves and exploited areas during the open season, but the decline was less precipitous in reserves. The decline in lobster abundance inside reserves during the fishing season indicates that the reserves are too small to adequately protect lobsters from harvest.

In Western Sambo ER, the mean size of legal lobsters and the frequency of occurrence of very large lobsters, especially males, increased steadily after protection was implemented in 1997. The overall abundance of spiny lobsters in the reserve varied without trend among years, but the abundance of legal-sized lobsters during the closed season increased significantly in the reserve relative to the exploited area (Cox and Hunt, 2005). It is apparent that some lobsters remain in this larger reserve for a long period of time, and it appears that a residential population of spiny lobsters is becoming established within the reserve. Western Sambo ER is an effective fishery reserve for spiny lobsters, presumably because of its larger size and protected status.

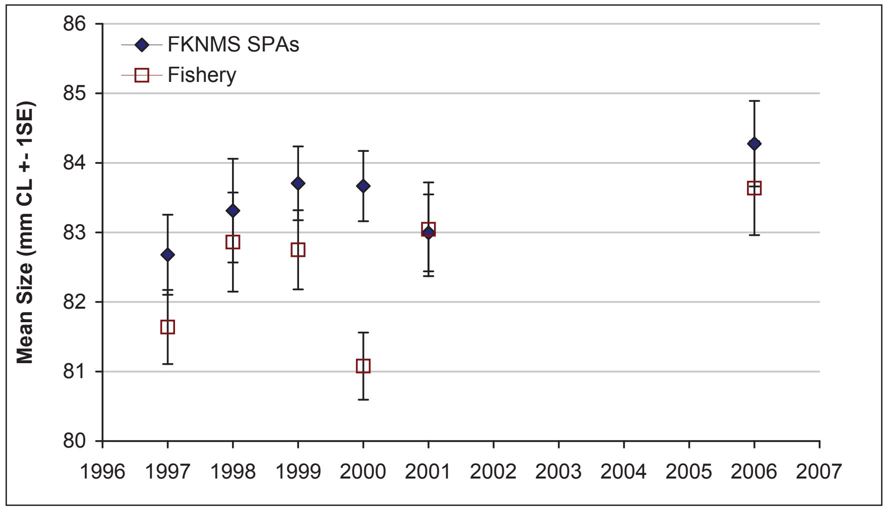

Figure 6.26. Size of legal (≥76 mm carapace length) lobsters in FKNMS SPAs (blue) and similar fished areas (red) during the closed fishing season (July). Source: Cox and Hunt, 2007.

FWC Queen Conch Monitoring in the Florida Keys

Methods

The FWC monitors the recovery of the queen conch (*Strombas gigas*) population in the Florida Keys by conducting belt-transects in locations with known conch aggregations, including marine reserves and adjacent reference areas. All conch within a 2 m belt-transect (laid out across an aggregation) were counted and mapped. Density and area estimates were used to determine population abundance. More information on data collection methods can be found in Glazer and Delgado (2003).

Results and Discussion

Since Florida's queen conch fishery was closed in 1986, there have been signs that adult queen conch have begun to recover (Glazer and Delgado, 2003; Figure 6.27). By 2003, adult conch density had increased to about 700 conch/ha yielding approximately 37,000 adults within breeding aggregations. However, this trend was reversed in 2004 and 2005 as density and overall abundance declined in both years. Since most of the breeding aggregations are in relatively shallow water (<5 m), the active hurricane seasons during these two years may have negatively impacted the aggregations. There was a slight rebound in density and overall abundance in 2006 to about 600 conch per ha and 25,500 adults.

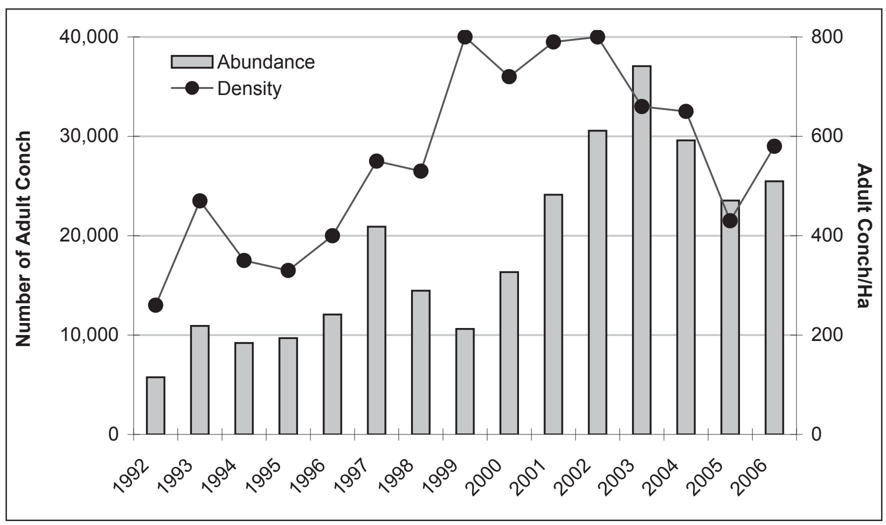

*Figure 6.27. Trends in the density and abundance of adult queen conch (*Strombus gigas*) in the Florida Keys, estimated from yearly monitoring of the breeding aggregations on the back reef. Source: Glazer and Delgado, 2003.*

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Mapping

In 2000, NOAA and the Fish and Wildlife Research Institute (FWRI) released habitat maps for the Florida Keys (Figure 6.28), representing the first large-scale effort to map coral ecosystem habitats in the Florida reef tract from Biscayne Bay to the Dry Tortugas. Habitats were delineated based on visual interpretation of 1991-1992 aerial photographs.

Shallow-water coral reef ecosystems of southern Florida encompass an estimated 30,800 km^2 and extend from the Dry Tortugas in the Florida Keys as far north as St. Lucie Inlet on the Atlantic Ocean coast and Tarpon Springs on the Gulf of Mexico coast (Rohmann et al., 2005). The collaborative Southern Florida Shallow-water Coral Ecosystem Mapping Implementation Plan (MIP), released in June 2005, discusses the need to produce shallow-water (about 0-40 m depth) benthic habitat and bathymetric maps of approximately 13,000 km^2 of critical areas in southern Florida (Figure 6.29). The plan was developed using extensive input from over 90 representatives of state regulatory and management agencies, federal agencies, universities and non-governmental organizations involved in the conservation and management of Florida's coral reef ecosystems. The MIP can be obtained at http://ccma.nos.noaa.gov/ecosystems/coralreef/fl_mapping.html.

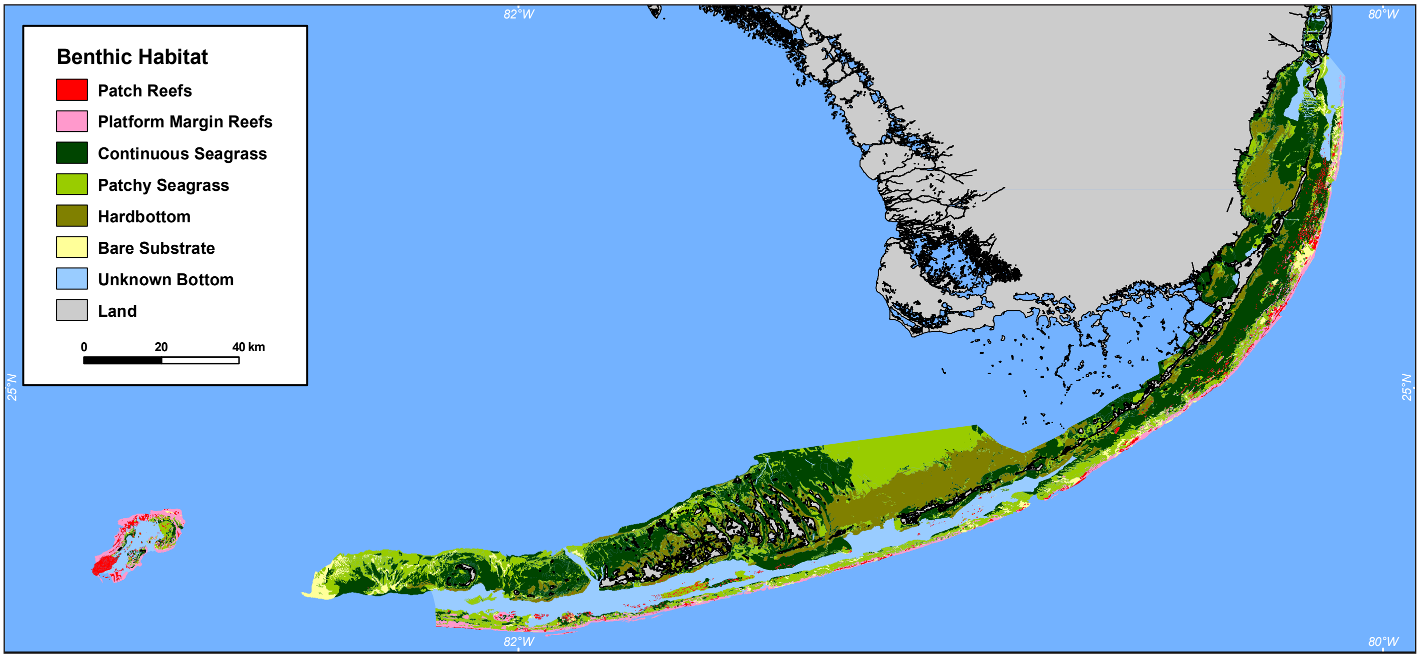

Figure 6.28. Nearshore habitat maps were developed by CCMA-BB based on visual interpretation of aerial photography and hyper-spectral imagery. The maps were released in 2000. For additional information, visit: http://biogeo.nos.noaa.gov. Map: K. Buja.

Since 2004, NOAA's Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB) has worked with state, university, and other federal partners to share the costs of gathering imagery and field data, manage contracts and other activities related to mapping coral reef ecosystems of southern Florida. Since 2005, CCMA-BB has purchased nearly 10,000 km^2 of color, high-resolution, commercial satellite imagery that will be used for delineating benthic habitats. Figure 6.30 shows satellite imagery available as a georeferenced mosaic for essentially 100% of the Florida Keys. While efforts were made to collect during optimal environmental conditions, the seafloor is not always visible in imagery as a result of widespread turbidity and some clouds. Several more years may be required to obtain suitable imagery of the entire area. NOAA has co-registered the color and panchromatic satellite imagery to Florida's 2004 Digital Orthophoto Quadrangles and is making it available through the NOS Data Explorer (http://oceanservice.noaa.gov/dataexplorer/whatsnew/welcome.html).

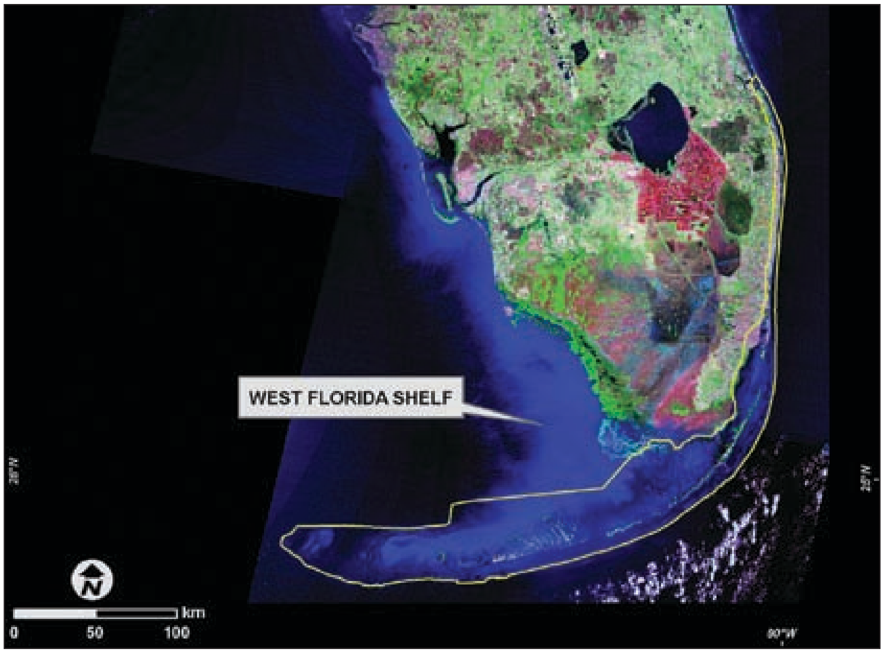

Figure 6.29. The yellow polygon delineates the approximately 13,000 km^2 priority shallow-water benthic habitat mapping area of southern Florida. Source: S. Rohmann, unpub. data.

Starting in 2007, NOS began producing maps of benthic habitats in the Hawk Channel portion of the Florida Keys. As of June 2008, draft maps have been completed for approximately 530 km^2 of Hawk Channel. A three-year grant from the Florida Wildlife Legacy Initiative to NOS will be used to map an additional estimated 975 km^2 of Hawk Channel. In the fall of 2008, NOS will begin mapping a further 335 km^2 of Hawk Channel. A benthic habitat map is considered draft until an independent accuracy assessment and peer review is completed. The NOS intends to work with NOVA Southeastern University's National Coral Reef Institute to conduct the accuracy assessment.

In April 2008, Florida's FWC plans to complete draft habitat maps of a portion of Biscayne Bay and the Dry Tortugas. This mapping activity, conducted in partnership with the NPS, will focus on the patch reefs found in these areas. High-resolution aerial photography, acquired in 2005, will provide the base imagery for the Biscayne Bay characterization. The satellite imagery discussed above will be used for the Dry Tortugas characterization.

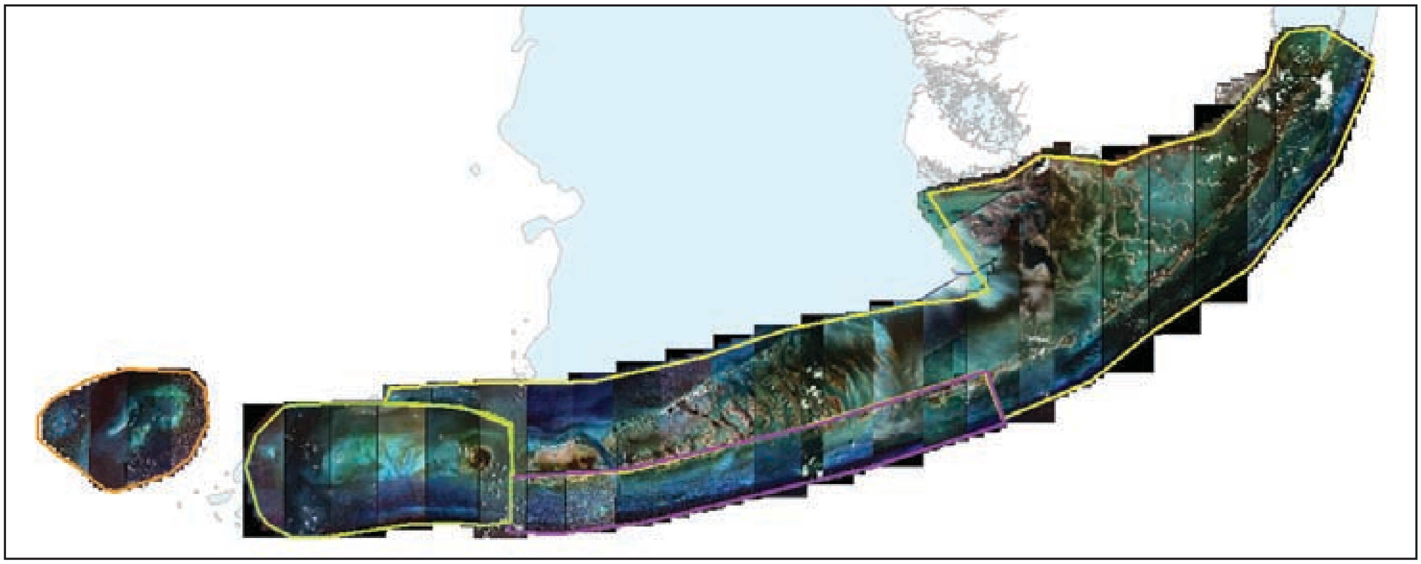

Figure 6.30. Satellite imagery collections of southern Florida as of November 2006. Source: S. Rohmann, unpub. data.

In April 2007, the NOS deployed a 25 ft boat equipped with an interferometric acoustic sonar system to collect bathymetry and associated side scan sonar imagery of the Hawk Channel in the Western Sambos Ecological Reserve southeast of Key West. Because it is not affected by turbidity, the interferometric sensor was able to collect data of the area despite poor water clarity conditions. NOS hopes to use these data to classify the more turbid portions of the Western Sambos.

Assessments, Monitoring and Research

Assessments, monitoring and research are conducted in the Florida Keys by many groups, including local, state and federal agencies, public and private universities, private research foundations, environmental organizations and independent researchers. Sanctuary staff facilitates and coordinates research by registering researchers through a permitting system, recruiting institutions for priority research activities, overseeing data management, and disseminating findings to the scientific community and the public.

The Water Quality Protection Program, which began in 1994 and is funded by U.S. Environmental Protection Agency, the USACE and NOAA gathers data on water quality, seagrasses, and coral reef and hard-bottom communities (Keller and Donahue, 2006). Information about these projects is provided throughout this report and at the following Web sites: http://ocean.floridamarine.org/fknms_wqpp/, http://serc.fiu.edu/wqmnetwork/FKNMS-CD/index.htm, http://www.fiu.edu/~seagrass/ and http://www.floridamarine.org/features/category_sub.asp?id=2360.

The Marine Zone Monitoring Program monitors a system of 24 marine reserves located within the FKNMS. Implemented in 1997, the goal of the program is to determine whether these fully protected zones effectively protect marine biodiversity and enhance human uses related to the sanctuary. Parameters measured include the abundance and size of fish and invertebrates, as well as economic and human dimensions of the sanctuary and compliance with regulations. This program monitors changes in ecosystem structure (size and number of invertebrates, fish, corals and other organisms) and function (coral recruitment, herbivory, predation). Human uses of zoned areas are also tracked. A summary report on findings of this monitoring program and other elements of the science program of the FKNMS is available online (Keller and Donahue, 2006; see also Cox and Hunt, 2005; and Ault et al., 2006).

MPAs and Fully Protected Areas

A significant addition to fully protected areas in the Florida Keys came with the authorization of the General Management Plan of the DTNP in January 2007, which includes a no-take Research Natural Area covering 158 km^2 (nearly half) of the DTNP. A monitoring plan for the Park including its newly revised zoning plan is being developed by NPS and FWRI staff.

Gaps in Monitoring and Conservation Capacity

A significant need in the Florida Keys is a complete, updated and high-resolution benthic habitat map as described in the mapping section above.

Coral Spawning Partnership 2007

An inaugural coral spawning research cruise was conducted in August of 2006, with the goals of initiating conservation-based coral research, continuing to educate scientists and students, and establishing an initial baseline of knowledge of coral spawning at Looe Key's Management Area, which has been federally protected since 1981. The cruise was operated by FKNMS and Florida's Department of Environmental Protection (FDEP) and supported 12 scientists and four students from various agencies including FDEP, EPA, NMFS, FWC, Mote Marine Laboratory, the University of Florida, the University of Texas at Austin, the FWRI and the World Wildlife Fund. Spawning observations of major reef building species are listed in Table 6.4. Participating scientists also took advantage of this event to initiate studies on coral reproduction, settlement and aquaculture of threatened coral species in the Florida Keys.

Table 6.4. The 2006 spawning observation timeline for reef building corals at Looe Key, Florida, USA. Source: Ritchie, unpub. data.

CORAL SPECIES	DAY 2*	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7	DAY 8	DAY 9
Acropora palmata	—	Pre-spawn	Full spawn 10:25 pm-11:15 pm	Intermed spawn 10:35 pm-11:15 pm	—	—	—	—
Acropora cervicornis	Post-spawn	—	—	—	—	—	—	—
Montastrea annularis	—	—	—	—	—	11:45 pm	11:25 pm-11:45 pm	—
Montastrea faveolata	—	—	—	—	—	9:55pm-12 am	Heavy spawn 11:11 pm-12:15 am	11:45 pm-12 am
Montastrea cavernosa	—	—	—	—	Pre-spawn	8:00 pm-10:00 pm	Post spawn	—
Diploria strigosa	—	—	—	—	—	10:35 pm-10:45 pm	8:30 pm-12:20 pm	Post spawn
Dendrogyra cylindricus	—	—	Male spawn 9:50 pm	—	—	—	—	—

*Days after the first full moon in August or 2006 (August 8th).

OVERALL CONCLUSIONS AND RECOMMENDATIONS

A large amount of coral cover has been lost in the Florida Keys over the past 12 years. Monitoring programs have shown an overall decline in hard coral cover of 44% at quantitatively surveyed stations. Proportionally, the major framework building corals seem to have been most affected (73% loss for *Acropora palmata*, and 37% loss for *Montastraea annularis*). Many of the causes of local coral decline originate beyond the jurisdiction of local resource managers. For example, algal blooms in the Florida Keys are influenced by nutrients and water flows from the Everglades and southwest Florida coast. Also, warming ocean temperatures associated with global climate change are a major factor in coral bleaching. Implementing solutions that will preserve the Florida Keys coral reef system will require action on regional and global scales.

The Florida Keys is host to several environmental monitoring programs and research projects that provide information useful for the development of protective policies and management strategies. Resource managers must actively work to collect information from these multiple sources, and also incorporate observations from local residents, to get a more complete picture of coral reef and related habitats.

Some of the most promising research may be in the areas of coral physiology, reproduction and genetics. These studies will provide information that helps predict responses to environmental conditions, identify etiology of coral diseases and increase the success of reef restoration projects.

The coral reef is a vital component of the tourism and fisheries-based economies of the Florida Keys, where millions of people congregate annually to enjoy the region's recreational experiences and seafood harvest. Continued protection of this important coral reef ecosystem will benefit from broad-based stewardship and greater public awareness and support.

REFERENCES

Andrews, K., N. Nall, C. Jeffrey, and S. Pittman. 2005. The State of Coral Reef Ecosystems of the Main Hawaiian Islands. pp. 222-269. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Aronson, R.B. and W.F. Precht. 2001. Applied paleoecology and the crisis on Caribbean coral reefs. Palaios 16: 195-196.

Ault, J.S., J.A. Bohnsack, and G. Meester. 1998. A retrospective (1979-1995) multispecies assessment of coral reef fish stocks in the Florida Keys. Fish. Bull. 96(3): 395-414.

Ault, J.S., S.G. Smith, G.A. Meester, J. Luo, and J.A. Bohnsack. 2001. Site Characterization for Biscayne National Park: Assessment of Fisheries Resources and Habitats. NOAA Technical Memorandum NMFS SEFSC 468. Miami, FL. 185 pp.

Ault, J.S., S.G. Smith, and J.A. Bohnsack. 2005a. Evaluation of average length as an indicator of exploitation status for the Florida coral-reef fish community. ICES J. Mar. Sci. 62: 417-423.

Ault, J.S., J.A. Bohnsack, S.G. Smith, and J. Luo. 2005b. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. Bull. Mar. Sci. 76(2): 595-622.

Ault, J.S., S.G. Smith, J.A. Bohnsack, J. Luo, D.E. Harper, and D.B. McClellan. 2006. Building sustainable fisheries in Florida's coral reef ecosystem: positive signs in the Dry Tortugas. Bull. Mar. Sci. 78(3): 633-654.

Bohnsack, J.A., D.E. Harper, and D.B. McClellan. 1994. Fisheries trends from Monroe County, Florida. Bull. Mar. Sci. 54: 982-1018.

Boyer, J.N. and H.O. Briceño. 2006. FY2005 Annual Report of the Water Quality Monitoring Project for the Florida Keys National Marine Sanctuary. Southeast Environmental Research Center Technical Report T-327. Florida International University. Miami, FL. 91 pp. http://serc.fiu.edu/wqmnetwork/Report%20Archive/2005FKNMS.pdf.

Boyer, J.N. and H.O. Briceño. 2007. FY2006 Annual Report of the Water Quality Monitoring Project for the Florida Keys National Marine Sanctuary. Southeast Environmental Research Center Technical Report T-354. Florida International University. Miami, FL. 77 pp. http://serc.fiu.edu/wqmnetwork/Report%20Archive/2006FKNMS.pdf.

Clark, C. 2006. Lobster fishermen stake it all on 2006 season. Miami Herald. Miami, FL. http://www.redorbit.com/news/business/605221/lobster_fishermen_stake_it_all_on_2006_season/index.html.

Cox, C. and J.H. Hunt. 2005. Change in size and abundance of Caribbean spiny lobsters *Panulirus argus*, in a marine reserve in the Florida Keys National Marine Sanctuary, USA. Mar. Ecol. Prog. Ser. 294: 227-239.

Cox, C. and J.H. Hunt. 2007. Caribbean spiny lobsters in Florida Keys National Marine Sanctuary Reserves - 10 years later. Abstract. p.141. In: 8th International Conference and Workshop on Lobster Biology and Management, Programme and Abstracts. Prince Edward Island, Canada. 158 pp.

Davis, G.E. 1977. Anchor damage to a coral reef on the coast of Florida. Biol. Conserv. 11(1): 29-34.

Davis, G.E. 1982. A century of natural change in coral distribution at the Dry Tortugas: A comparison of reef maps from 1881 and 1976. Bull. Mar. Sci. 32: 608–623.

Florida Department of Environmental Protection and National Oceanic and Atmospheric Administration (FDEP and NOAA). 1998. Benthic habitats of the Florida Keys. FMRI Technical Report TR-4. Florida Marine Research Institute. St. Petersburg, FL. 53 pp.

Florida Fish and Wildlife Conservation Commission (FWC). 2007. Fishing Capital of the World. http://fishingcapital.com/.

Frank, K.T., B. Petrie, J.S. Choi, and W.C. Leggett. 2005. Trophic cascades in a formerly cod-dominated ecosystem. Science 308(5728): 1621-1623.

Gardner, T.A., I.M. Côté, J.A. Gill, A. Grant, and A.R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. Science 301(958): 958-960

Garrett, G. Monroe County Division of Marine Resources. Marathon, FL. Personal communication.

Glazer, R.A and G.A. Delgado. 2003. Towards a holistic strategy to managing Florida's queen conch (*Strombus gigas*) population. pp. 73-80. In: D. Aldana Aranda (ed.). El Caracol Strombus gigas: Conocimiento Integral para su Manejo Sustentable en el Caribe. CYTED, Programa Iberoamericano de Ciencia y Technología para el Desarrollo. Yucatán, México. 165 pp.

Harper, D.E., J.A. Bohnsack, and B. Lockwood. 2000. Recreational Fisheries in Biscayne National Park, Florida, 1976-1991. Mar. Fish. Rev. 62: 8-26.

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2001. Socioeconomic Study of Reefs in Southeast Florida, Final Report. Technical Report 01-10. Broward County Environmental Protection Department. FL. 348 pp. http://www.broward.org/environment/bri01714.pdf.

Johns, G.M., J.W. Milon, and D. Sayers. 2004. Socioeconomic Study of Reefs in Martin County, Florida. Final Report. Martin County, FL. 120 pp. http://marineeconomics.noaa.gov/Reefs/MartinCounty2004.pdf.

Keller, B.D. and S. Donahue (eds.). 2006. 2002-03 Florida Keys National Marine Sanctuary science report: an ecosystem report card after five years of marine zoning. Marine Sanctuaries Conservation Series NMSP 06-12. NOAA National Marine Sanctuary Program. Silver Spring, MD. 358 pp. http://sanctuaries.noaa.gov/science/conservation/fk_report.html.

Kimball, M.E., J.M. Miller, P.E. Whitfield, and J.A. Hare. 2004. Thermal tolerance and potential distribution of invasive lionfish (*Pterois volitans*/miles/complex) on the east coast of the United States. Mar. Ecol. Prog. Ser. 283: 269-278.

Leeworthy, V.R., T. Maher, and E.A. Stone. 2006. Can Artificial Reefs Alter User Pressure on Adjacent Natural Reefs? Bull. Mar. Sci. 78(1): 29-37.

Mace, P. 1997. Developing and sustaining world fishery resources: state of science and management. pp. 1-20. In: D.A. Hancock, D.C. Smith, A. Grant, and J.P. Beumer (eds.). Proceedings of the Second World Fishery Congress. Brisbane, Australia. 797 pp.

McClenachan, L. 2008. Social conflict, overfishing and disease in the Florida sponge fishery. pp. 1849-1939. In: D. Starkey (ed.). Oceans Past: Management Insights from the History of Marine Animal Populations. Earthscan Publications Limited, London. 250 pp.

Miller, M.W. (compiler). 2002. Acropora corals in Florida: Status, trends, conservation, and prospects for recovery. pp. 59-70 In: A.W. Bruckner (ed.). Proceedings of the Caribbean Acropora workshop: potential application of the U.S. Endangered Species Act as a conservation strategy. NOAA Technical Memorandum NMFS OPR 24. Silver Spring, MD.

Miller, S.L., M. Chiappone, L.M. Rutten, D.W. Swanson, and R. Waara. 2006a. Surveys of benthic coral reef organisms in Dry Tortugas Park and the Tortugas Bank, western Florida Keys National Marine Sanctuary. Quick Look Report: Tortugas Region Cruise. Center for Marine Science. University of North Carolina at Wilmington. Wilmington, NC. 10 pp. http://people.uncw.edu/millers/CoralReef_QuickLooks.htm.

Miller, S.L., M. Chiappone, L.M. Rutten, and D.W. Swanson. 2006b. Population assessment of staghorn (*Acropora cervicornis*) and elkhorn corals (*A. palmata*) in the upper Keys region of the Florida Keys National Marine Sanctuary. 2006 Quick Look Report: Acropora. Center for Marine Science. University of North Carolina at Wilmington, NC. 7 pp. http://people.uncw.edu/millers/CoralReef_QuickLooks.htm.

National Marine Fisheries Service (NMFS). 2005. Status of Fisheries of the United States - Report to Congress. http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm.

National Marine Fisheries Service (NMFS). 2007. Marine Recreational Fisheries Statistics Survey (MRFSS). Fisheries Statistics Division, NOAA NMFS Office of Science and Technology. Silver Spring, MD. http://www.st.nmfs.noaa.gov/st1/index.html.

National Oceanic and Atmospheric Administration (NOAA). 1998. Benthic Habitats of the Florida Keys digital data product. Special Projects Office. Silver Spring, MD. ftp://spo.nos.noaa.gov/datasets/benthic_habitats.

Oppel, F. and T. Meisel. 1871. Along the Florida Reef. pp. 265-309. In: Tales of Old Florida. Castle Press. Seacaucus, NJ. 480 pp.

Porch, C.E., A.M. Eklund, and G.P. Scott. 2003. An assessment of rebuilding times for goliath grouper. SEDAR6-RW-3. Sustainable Fisheries Division, NMFS Southeast Fisheries Science Center. Miami, FL. 25 pp. http://www.sefsc.noaa.gov/sedar/.

Porch, C.E., A.M. Eklund, and G.P. Scott. 2006. A catch-free stock assessment model with application to goliath grouper (*Epinephelus itajara*) off southern Florida. Fish. Bull. 104: 89-106.

Reef Environmental Education Foundation. 2006. Online database. http://www.reef.org/programs/exotic.

Rohmann, S.O., J.J. Hayes, R.C. Newhall, M.E. Monaco, and R.W. Grigg. 2005. The area of potential shallow-water tropical and subtropical coral ecosystems in the United States. Coral Reefs 24(3): 370-383.

Semmens, B.X., E.R. Buhle, A.K. Salomon, and C.V. Pattengill-Semmens. 2004. Tankers or fish tanks: what brought non-native marine fishes to Florida waters. Mar. Ecol. Prog. Ser. 266: 239-244.

Sheridan, P., R. Hill, G. Matthews, R. Appeldoorn, B. Kojis, and T. Matthews. 2005. Does trap fishing impact coral reef ecosystems? An update. pp. 511-519. In: Proceedings of the 56th Gulf and Caribbean Fisheries Institute. Tortola, British Virgin Islands. 851 pp.

Waddell, J.E. (ed.). 2005. The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Wilkinson, C.R. 1996. Global change and coral reefs: Impacts on reefs, economies and human cultures. Global Change Biol. 2(6): 547-558.

Williams, D.E., M.W. Miller, and K.L. Kramer. 2006. Demographic monitoring protocols for threatened Caribbean *Acropora* spp. corals. NOAA Technical Memorandum NMFS SEFSC 543. Miami, FL. 91 pp.