The State of Coral Reef Ecosystems of Florida

Edited by:
Katherine Andrews[1], Larry Nall[1], Chris Jeffrey[2], Simon Pittman[2]

Contributing Authors:
Ken Banks[3], Carl Beaver[4], James Bohnsack[5], Richard E. Dodge[6,7], David Gilliam[6,7], Walt Jaap[4], Brian Keller[8], V. Robert Leeworthy[9], Tom Matthews[4], Ramon Ruiz-Carus[4], Deborah Santavy[10], Richard Spieler[6,7]

Other Contributors:
Jerald Ault[11], Gabriel Delgado[4], Fleur Ferro[8], Carol R. Fretwell[7], Bill Goodwin[8], Doug Harper[5], John Hunt[4], Margaret Miller[5], Christy Pattengil-Semmens[12], Bill Sharp[4], Steve Smith[11], Jennifer Wheaton[4], Dana Williams[5]

INTRODUCTION AND SETTING

Florida is located at the convergence of the subtropical and temperate climate zones (Chen and Gerber, 1990). The Gulfstream (a warm-water boundary current) has a major influence on water temperature and the transport of flora and fauna to the region (Jaap and Hallock, 1990). The Gulfstream intrudes into the Gulf of Mexico as the Loop Current and reverses flow to return to the Straits of Florida, joining the main body of the Florida Current before flowing in a northeasterly direction towards Europe. The influence of the Gulfstream together with the presence of a broad-shallow continental shelf around Florida and the absence of any major rivers have provided conditions for the development of extensive coral reefs (Figure 7.1). Most coral reefs are found in water less than 18 m deep. Rohmann et al. (in press) have estimated that 30,801 km^2 of shallow-water inshore areas around Florida could potentially support coral reef ecosystems. In comparison, the area estimated was 16.4 km^2 in Guam, 1,231.4 km^2 in the Main Hawaiian Islands and 2,207.6 km^2 in Puerto Rico.

Florida Reef Tract

The Florida Reef Tract, which extends from Soldier Key to Tortugas Banks, has coral reef characteristics similar to many areas in the Bahamas and Caribbean Basin (Vaughan, 1914). The undeveloped coastal fringe includes extensive mangrove forests and a mosaic of exposed rock and sediments. Elevated rock formations support coral reef development and the sediments support the most extensive seagrass beds in the world (Fourqurean et al., 2002).

Three types of coral reef habitats found in the Florida Keys are hardbottom, patch reefs, and bank reefs (Table 7.1). Hardbottom or live bottom habitat is the most extensive habitat type, found at a wide range of water depths and characterized by rock colonized with calcifying algae (e.g., *Halimeda* spp.), sponges, octocorals, and several species of stony coral. Local environmental conditions determine the composition of the communities that colonize the rock. Patch reefs typically consist of massive stony corals, with the boulder star coral (*Montastraea annularis*) being most dominant. Other common foundation-building species include *Colpophyllia natans* and *Siderastrea siderea*. Patch reefs are concentrated in north Key Largo, Hawk Channel between Marathon Key and Key West, and the area off Elliott Key. Species diversity and richness of stony corals are highest in patch reef habitats (Jaap et al., 2003). Bank reefs are the most seaward of coral reef habitats in the Florida Keys coastal ecosystem and are frequently visited by recreational scuba divers and snorkelers. Their principal unique feature is the spur-and-groove system, a series of ridges and channels built primarily by elkhorn coral (*Acropora palmata*) (Shinn, 1963). Spur-and-groove systems occur in depths ranging from a few centimeters to 10 m. In deeper waters, spur-and-groove formations may continue seaward as very low relief structures. Often, this type of habitat is referred to as the forereef and may continue to about 30 m in depth. Seaward, sediments separate the fore-reef from deeper reef formations at a depth of about 40 m.

1 Florida Department of Environmental Protection
2 NOAA, Center for Coastal Monitoring and Assessment, Biogeography Team
3 Broward County Environmental Protection Department
4 Florida Fish and Wildlife Conservation Commission
5 NOAA Fisheries, Southeast Fisheries Science Center
6 Nova Southeastern University Oceanographic Center
7 National Coral Reef Institute
8 Florida Keys National Marine Sanctuary
9 NOAA Ocean Service, Special Projects Office
10 U.S. Environmental Protection Agency, Gulf Ecology Division
11 University of Miami, Rosenstiel School of Marine and Atmospheric Sciences
12 Reef Environmental Education Foundation

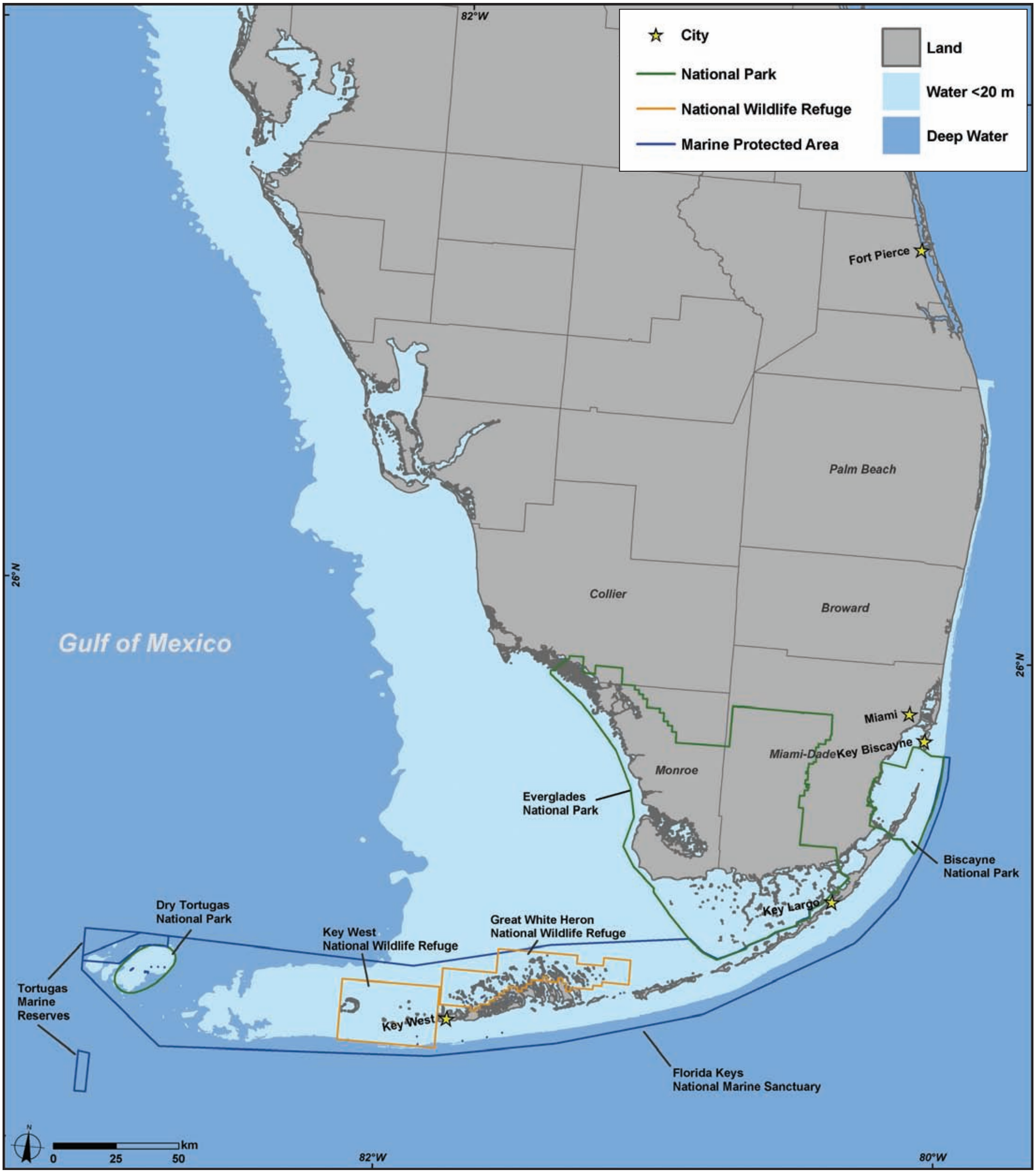

Figure 7.1. Locator map for Florida. Map: A. Shapiro.

Tortugas Banks

The Tortugas Banks are coral reefs that developed on a foundation of Pleistocene karst limestone at depths of 20-40 m. The banks are extensive with low coral diversity, but high coral cover. The most conspicuous coral is *Montastraea cavernosa,* and black coral (Antipatharia) are common on the outer bank edges. The banks are also used by groupers and snappers that support a major fishery.

The Southeastern Coast

This reef system continues the Florida reef tract northwards and runs from northern Monroe County to Martin County in a series of discontinuous reefs paralleling the shore. Duane and Meisberger (1969) and Goldberg (1973) defined the habitat including corals at several locations. Moyer et al. (2003) investigated the ecological and spatial patterns of the benthos on various reefs of Southeast Florida (Broward County; Figure 7.2).

Table 7.1. Habitat area estimates for the Florida Reef Tract. Source: FMRI 1998.

TYPE OF REEF HABITAT	HECTARES	KM^2	ACRES
Hardbottom	82370	824	203540
Patch Reef	3370	34	8330
Bank Reef	29550	295	73010
Total coral reef estimate	115290	1153	284880
Seagrass	292520	2925	722840

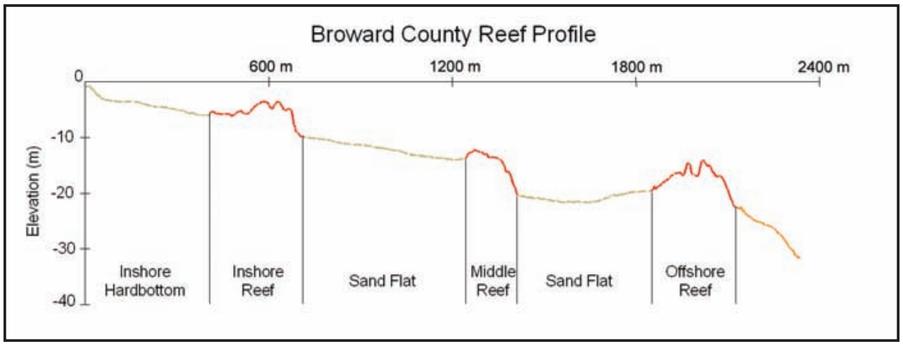

Figure 7.2. A reef profile along a shore-perpendicular transect of high resolution bathymetry data from 0-30m depth off central Broward County. The x-axis represents distance from shore in meters and y-axis represents elevation in meters. The seafloor of the profile is categorized in the sections below the profile line. The red line along the profile represents the three main shore-parallel reef tracts. Source: R. Dodge, National Coral Reef Institute, http://www.nova.edu/ocean/ncri/, Accessed 1/6/2005.

In addition to nearshore hardbottom areas, there are generally three lines of reef – one that nominally crests in 3-4 m of water (inner reef), another in 6-8 m (middle reef), and a third in 15-21 m (outer reef). A series of ridges that are not reefal in origin occur on the shoreward side of inner reef areas (Moyer et al., 2003).

Inner reefs are characterized by macroalgae and numerous small octocorals. The substrate is relict reef of Anastasia Formation limestone and worm reef (*Phragmatopoma* spp.), with breaks and sediment pockets within the reef. Typical sessile organisms are lesser starlet coral (*Siderastrea radians*) and colonial zoanthids (*Palythoa mammilosa* and *P. caribaeorum*). In the past few years, vigorous recruitment of staghorn coral (*Acropora cervicornis*) have occurred, and some extensive aggregations are now present generally inshore of inner reefs in Broward County. Here, monospecific stands of coral form significant habitats (Vargas-Ángel et al., 2003). Spawning activity has been documented in late July to early August (Vargas-Ángel and Thomas, 2002; Vargas-Ángel et al., in prep.).

Middle reefs have more relief and dissecting channels. Octocorals are most conspicuous, with densities of more than 30 per m^2 in some areas. Abundant stony corals include great star coral (*Montastraea cavernosa*), massive starlet coral (*Siderastrea siderea*), and mustard hill coral (*Porites astreoides)* (Gilliam et al., 2003).

The outer reef system often has stronger vertical relief and exhibits the highest diversity and abundance of sessile reef organisms. Octocorals and large barrel sponges (*Xestospongia muta*) are most conspicuous and visually dominate this reef. Stony corals are somewhat larger than those located on the middle reef. Moderate-sized colonies of star corals are common.

The reef system at St. Lucie Inlet Preserve State Park (27°05´ to 27°09´ N) is the northern limit for subtropical coral reefs on the east coast of Florida. The topography is composed of Anastasia Formation limestone that is covered with reef biota. *Diploria clivosa* forms very large pancake-like colonies and provides the majority of the cover. *Montastraea cavernosa* also attains large sizes. The other species present - *Siderastrea radians, Isophyllia sinuosa, Solenastrea bournoni,* and *Oculina diffusa* - are not large. Stony corals accounted for 3-5% of benthic cover at two 100-m transects (Herren, 2004).

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Coral reefs in Florida face a number of different stressors. These include coral bleaching, diseases, water pollution, physical impacts (such as groundings, dredging activities, and beach renourishment), tropical storms, and winter cold fronts. Other stressors of less concern in Florida include national security activities and trade in coral species.

Climate Change and Coral Bleaching

Coral bleaching due to exceptionally high water temperatures has been reported in Florida since the early 20th century (Vaughan, 1911; Mayer, 1918). Jaap (1979, 1984) also reported coral bleaching events in the Lower Keys following late summer doldrums when water temperatures exceeded 31ºC. Other significant and severe bleaching events on reefs throughout Florida occurred in 1987, 1990, and 1997-98 (Causey, 2001). These bleaching events have caused moderate mortality of the more sensitive stony corals, *Millepora complanata* and *Agaricia agaricites*. Bleaching episodes have become much more severe in space and time in the past few decades.

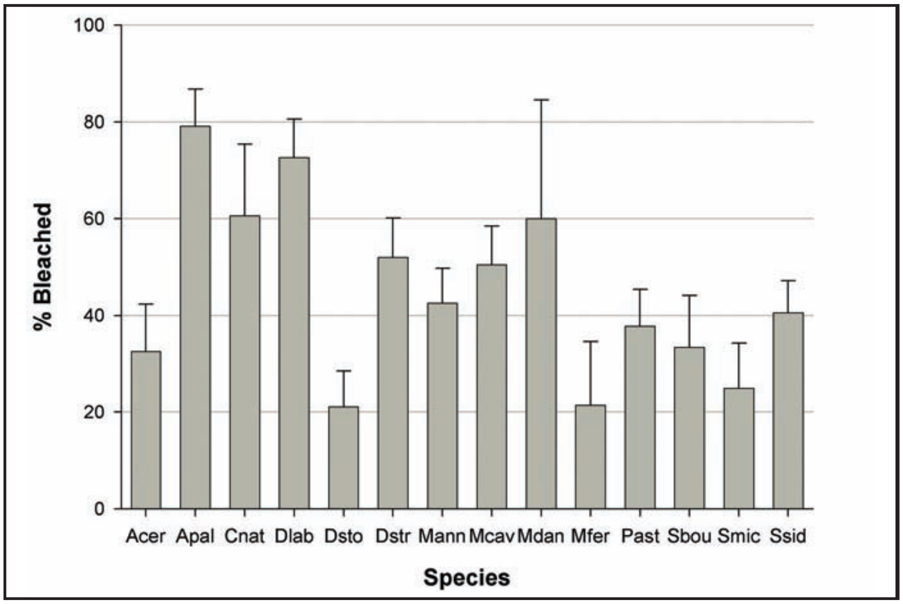

Figure 7.3. Mean percentage of coral colonies that were greater than 50% bleached identified by species assessed in September 1998 in the Lower Keys and the Dry Tortugas sites. Error bars represent 1 SE. X axis legend: Acer: *Acropora cervicornis*; Apal: *A. palmata*; Cnat: *Colpophyllia natans*; Dlab: *Diploria labyrinthiformis*; Dsto: *Dichocoenia stokesii*; Dstr: *Diploria strigosa*; Mann. *Montastraea annularis*; Mcav: *Montastraea cavernosa*; Mdan: *Meandrina danae*; Mfer: *Mycetophyllia ferox*; Past: *Porites astreoides*; Sbou: *Solenastrea bournoni*; Smic: *Stephanocoenia michelinii*; Ssid: *Siderastrea siderea*. Source: Santavy et al., 2001.

Coral bleaching assessments were made during the 1998 global bleaching event by the U.S. Environmental Protection Agency's (EPA) Gulf Ecology Division, in collaboration with the National Oceanic and Atmospheric Administration's (NOAA) Florida Keys National Marine Sanctuary (FKNMS), Mote Marine Laboratory's Center for Tropical Research, and University of Georgia. Surveys were conducted in the Florida Keys, with sites in the Lower Keys, New Grounds, and Dry Tortugas. Details of the sampling design, approach, and methods are described in Santavy et al. (2001). Bleaching was scored if greater than 50% of a coral colony had translucent white tissue present. Every species recorded in this assessment was observed to be bleaching. At least 50% of the colonies of the species *Acropora palmata, Diploria labyrinthiformis, D. strigosa, Colpophyllia natans, Mycetophyllia danaana* and *Montastraea cavernosa* were over 50% bleached (Figure 7.3). Reefs in the Lower Keys exhibited the greatest bleaching (43% ± 5.7 SE) compared to reefs in the Dry Tortugas and New

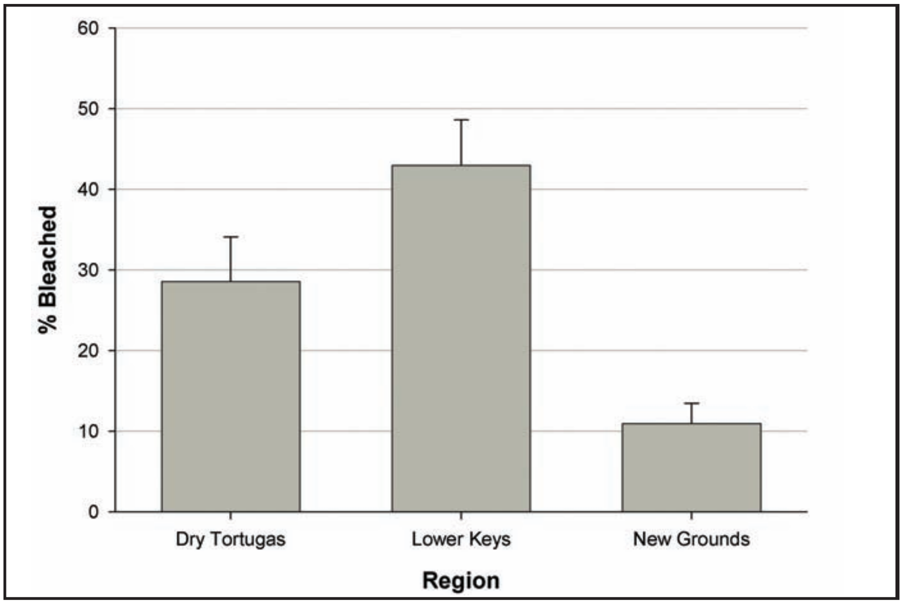

Figure 7.4. Mean percentage of coral colonies that were greater than 50% bleached assessed in September 1998 in the Dry Tortugas, Lower Keys, and New Grounds. Error bars represent 1 SE. Source: Santavy et al., 2001.

Grounds (Figure 7.4). Shortly after the assessments, Hurricane Georges passed over Key West as a Class 3 hurricane which caused substantial physical destruction. The stress from intense bleaching and Hurricane Georges was responsible for significant coral mortality that occurred between surveys in late summer 1998 and late spring 1999. Detailed information concerning bleaching distributions are reported in Santavy et al. (2001).

Disease

Surveys conducted along the Florida Keys Reef Tract during 1998-2002 assessed coral diseases for several applications. The first application was to determine the frequency and distribution of coral condition, using coral disease as the indicator to determine the overall health of corals. This approach was applied during the 2000 survey. The second application was to compare coral diseases between geographical regions in the Dry Tortugas, New Grounds, Key West region, Lower Keys, Middle Keys, and Upper Keys. Coral diseases were assessed by scientists from EPA's Gulf Ecology Division, FKNMS, and Mote Marine Laboratory's Center for Tropical Research. In general, diseases were most abundant in 1998, with observed changes in species composition which suggest that corals are increasingly dying and not recovering. In extreme cases, there has been almost complete deterioration of several keystone species, most notably *Acropora palmata* (Patterson et al., 2002). Although it is clear that new diseases are emerging at an accelerated rate, cause and effect relationships are not well documented. Coral health and diseases have not been critically or thoroughly characterized, and few baseline studies have been conducted in this region. More information about the results of coral disease studies can be found in the 'Benthic Habitats' section.

Tropical Storms

Storms are a normal part of the South Florida ecosystem because of the close proximity of Florida to the Caribbean Basin, where intense hurricanes develop seasonally. Hurricanes that have impacted Florida since 1979 are shown in Figure 7.5. Tropical storms can be a major force structuring coral reef communities through processes such as direct physical impact, increased terrestrial runoff, sedimentation, and pollution. For example, Hurricane Georges (1998) broke and reduced to rubble many large branching elkhorn and staghorn corals which were already weakened by disease (USGS, 1998; AOML, 1999). In 2004, various parts of Florida's coastline were hit by four major hurricanes (Charley, Francis, Ivan, and Jeanne). Hurricane Charley caused moderate damage to coral reefs at Dry Tortugas and off Broward. For instance, at the northeast side of Loggerhead Key, a patch of *Acropora cervicornis* was broken into small pieces and washed inshore; however, a month later surviving fragments appeared healthy. On Bird Key Reef, many large coral formations were dislodged and abundance of benthic algae was drastically reduced on most

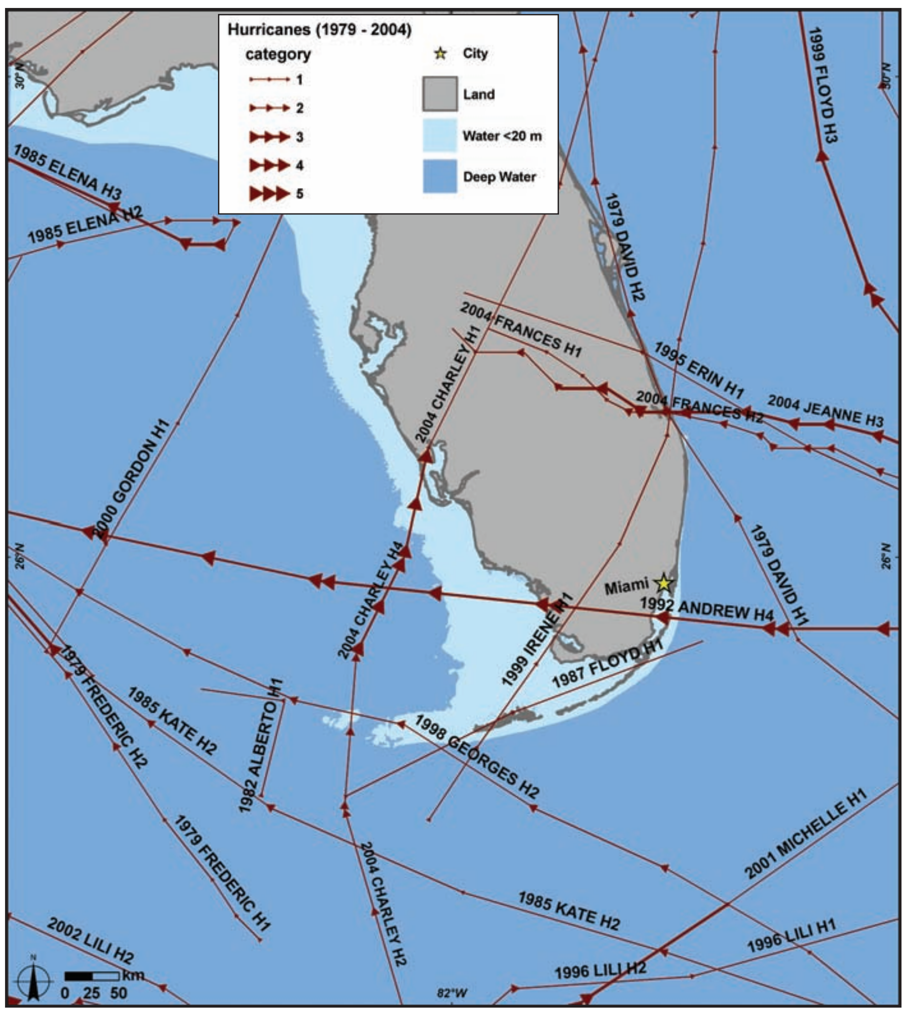

Figure 7.5. The paths and intensities of hurricanes in Florida, 1979-2004. Year of storm, hurricane name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

of the reefs visited after the storm (W.C. Japp, pers. obs.). Hurricanes Francis and Jeanne caused damage to coral reefs off Palm Beach and Martin Counties (W.C. Japp, pers. obs.).

Nevertheless, tropical storms may have beneficial effects on coral reef ecosystems off Florida's southeast coastline. Florida Bay is very shallow (1 m), with a myriad of banks and shoals that quickly dissipate tidal exchanges and prevent regular flushing of the bay. Reduced tidal flushing has contributed to the accumulation of organic matter, sediments, and nutrients which promote phytoplankton blooms that decrease the amount of light available to seagrass beds (AOML, 1999). Increased storm surge and wave action from powerful hurricanes increase tidal flushing, reduce sedimentation and are thought to reduce phytoplankton blooms (AOML, 1999). After Hurricane Georges (1998), however, water quality conditions were not significantly different than before because nutrient-enriched waters remained trapped within Florida Bay by broad, shallow banks in the central and western portions of the bay (AOML, 1999). Additionally, Lirman (2003) found that the abundance of *A. palmata* correlated positively with an increase in storm frequency from one storm every 15 years to one storm every two years, but declined with a further increase in storm frequency. Successful survivorship, reattachment, and growth of coral fragments after storm events may be the only means of propagation for *A. palmata* when sexual recruitment is limited (Lirman, 2003). However, the synergistic effects of multiple stressors (e.g., disease, coastal pollution, and overgrowth by algae) could prevent normal patterns of recovery in corals after storm events (USGS, 1998).

Coastal Development and Runoff

The reefs of mainland Southeast Florida, by virtue of their high latitude and proximity to shore, exist at the environmental extremes for corals. Natural phenomena, such as cold weather fronts; upwelling of cold, nutrient-rich waters; and freshwater runoff from land all contribute to "pushing the environmental limits" for corals and other reef-associated organisms. Anthropogenic activity that leads to a reduction in water quality may result in further physiological stress to corals and adversely impact coral reef ecosystems.

Nonpoint sources of pollution include surface water runoff, storm water discharge, and groundwater seeps. The nonpoint-source pollution may be delivered to the reef directly, as in the case of runoff, through navigational inlets and passes, and through the porous limestone substrate underlying south Florida. Nutrient loading of nitrogen and phosphorus from inland agriculture to the coastal waters offshore of Palm Beach County (mainland Southeast Florida) via surface water discharge are 2,473 and 197 metric tons (mt) per year, respectively, and via submarine groundwater discharge are 5,727 and 414 (mt) per year, respectively (Finkl and Charlier, 2003; Finkl and Krupa, 2003). Studies have estimated that groundwater from the interior parts of South Florida can take five to eight decades to reach the nearshore zone (Finkl and Charlier, 2003). Furthermore, run-off from the Everglades via Florida Bay and the Keys has been found to impact water quality around the Keys (Boyer and Jones, 2002).

Coastal Pollution

The effects of coastal pollution on reef-associated communities are not entirely understood. One obvious impact, however, is an increase in the magnitude and persistence of macroalgal blooms, which have increased worldwide during the past several decades (Morand and Briand, 1996). There is evidence that blooms may be a result of nutrient loading from land-based sources (NRC, 2000). Lapointe (1997) and Lapointe and Barile (2001) linked nitrogen from land-based sewage to macroalgal blooms in Southeast Florida. In Southeast Florida, harmful macroalgal blooms have occurred extensively in the offshore waters of Palm Beach County during the past decade (Lapointe and Barile, 2003), and over the past two years the cyanobacterium (*Lyngbya confervoides*) has covered an extensive area of the middle reef tract offshore Broward County. These blooms have had a significant impact on reef-associated organisms (Lapointe, 1997). The impacts include smothering and resultant mortality, as well as substrates dominated by macroalgae that would naturally be colonized by other organisms, such as corals and sponges. Researchers in Barbados (Tomascik, 1991; Wittenberg and Hunte, 1992) reported decreased coral larval settlement on reefs in nutrient-rich waters. Other impacts of water pollution on reef communities include increased bioerosion rates (reviewed by Risk et al., 2001) and possible links to coral diseases. Patterson et al. (2002) identified the human fecal bacterium *(Serratia marcescens*) as the causal agent of white pox disease in corals in the Florida Keys, and Bruno et al. (2003) reported evidence of nutrient enrichment increasing the severity of disease in sea fans and some coral species.

An extensive water quality monitoring program for the Florida Keys and Florida Bay underway since 1995 (Boyer and Jones, 2003) has reported elevated nitrogen levels in the nearshore areas of the Keys but not in the Tortugas region, suggesting a relationship with land-use patterns. No coastal water quality monitoring is underway for the mainland Southeast Florida region. There is a great need for such a monitoring program, particularly in light of the number of extensive macroalgal blooms that have occurred on mainland reefs in recent years. In addition to monitoring, further research to identify cause-and-effect relationships (i.e., water quality and reef community response) are needed.

The most extensive program underway to reduce water pollution is the National Pollution Discharge Elimination System (NPDES), a Federal program to regulate pollution from point source and stormwater discharges into receiving waters. The NPDES program is mandated in the Federal Clean Water Act (33 U.S.C. § 1251 et seq.) and is administered by the EPA and delegated to states, including Florida. Industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters. Facilities discharging stormwater must meet appropriate treatment criteria and may not cause or contribute to a violation of water quality standards. The program has been effective in requiring many private small wastewater treatment plants to eliminate raw sewage discharges. All municipal wastewater treatment plants must attain minimum levels of effluent quality using secondary treatment, including facilities with ocean outfalls. Water quality standards need to be re-evaluated from a perspective that addresses impacts to coral reef systems.

Wastewater in the Florida Keys is handled by approximately 200 treatment plants and numerous private septic tanks. Because of the low land elevation in the Keys, the septic tank drain fields are under tidal influence and nutrient-rich water leaches through the porous limestone into coastal waters. In order to decrease this nutrient loading, Monroe County is undertaking a study of the septic tank problem and consolidation of the wastewater plants into regional facilities.

Tourism and Recreation

Florida's coral reefs are located near the four most densely populated counties of the state (U.S. Census Bureau, 2003). The combined population of these four counties is more than five million, with 2.3 million in Miami-Dade, 80,000 in Monroe, 1.7 million in Broward, and 1.2 million in Palm Beach County (U.S. Census Bureau, 2003). Tourism is Florida's top industry and generates over $50 billion a year for the state's economy. In 2003, Florida hosted over 74 million visitors who participated in reef-based recreation, generating $18 million annually in the Florida Keys (VISIT FLORIDA Year-in-Brief, 2003). Reef tourism is a significant economic asset in Palm Beach, Broward, Miami-Dade, and Monroe Counties, which are all on the list of top ten destination counties for tourists to Florida (Johns et al., 2001; VISIT FLORIDA Year-in-Brief, 2003). The primary tourism activities include snorkeling, scuba diving, fishing, glass bottom boat tours, boat rentals, dive training, and dive shop sales (Table 7.2). By far, the largest economic benefits generated by direct use of the reefs of Southeast Florida are related to recreation and tourist activities. For example, in the June 2000 to May 2001 tourist season, tourism generated over $16 billion in output/sales, including local multiplier impacts. These sales, in turn, generated an estimated $6.2 billion in income, which supported over 251,000 full-time and part-time jobs. In Florida, the Monroe County economy is the most highly dependent on tourism, with 61% of all county employment related to tourist activity.

Johns et al. (2001) estimated direct use of both the artificial and natural reefs and the associated market and non-market economic use values for Southeast Florida. For the four-county area, direct use of natural reefs by both residents and visitors was estimated at 18.4 million person-days of snorkeling, scuba diving, fishing, and viewing coral reefs from glass-bottom boats, which resulted in over $2.7 billion in output/sales (Table 7.2). This activity further generated over $1.2 billion in income that supported over 43,000 full-time and part-time jobs. Annual net direct user value of natural reefs was over $229 million. Residents and visitors to the Florida Keys (Monroe County) spent about 3.9 million person-days of diving, fishing, and viewing coral reefs and $373 million in local sales, which generated about $107 million in income locally that supported over 7,600 jobs. In addition to these economic impacts, users received over $57 million in net annual user value, with an asset value of $1.9 billion.

In Palm Beach County, users spent over 2.8 million person-days on the natural reefs off the coast of the county with economic impacts on the county of $354 million in sales, which generated $141 million in local income and supported 4,500 jobs. Reefs off Palm Beach County had a net annual user value of over $42 million, with an asset value of $1.4 billion. In Broward County, users spent about 5.4 million person-days on the natural reefs, spent $1.1 billion, generated $547 million in local income, and supported about 18,600 jobs (Table 7.2). Reefs off Broward County had a net annual user value of about $83 million and an asset value of $2.8 billion. In Miami-Dade County, users spent over 6.3 million person-days on the natural reefs, generated $878 million in sales and $419 million in income locally, and supported about 12,600 jobs. The reefs of Miami-Dade had a net annual user value of almost $47 million, with an asset value of $1.6 billion (Table 7.2).

Table 7.2. Estimates by county of area and monetary value of recreational and tourism-related activities occurring in coral reef ecosystems of Southeastern Florida, 2000-2001. Source: Johns et al., 2001.

ATTRIBUTE	BROWARD	MIAMI-DADE	MONROE	PALM BEACH
Habitat area (x 1000 hectares)	8.3	7.2	115.3	12.0
Person days of activity (millions of days)	5.4	6.3	3.9	2.8
Sales and Services (millions of $)	1100	878	373	354
Income (millions of $)	547	419	107	141
Number of jobs	18,600	12,600	7,600	4,500
Asset value (millions of $)	2,800	1,600	1,900	1,400
Snorkeling (millions of $)	0.8	1.5	1.5	0.4
Scuba diving (millions of $)	2	0.7	0.5	1.3
Fishing (millions of $)	2.6	4.1	1.8	1.1
Glass-bottom boat rides (millions of $)	0.04	0.01	0.07	0

Fishing

Coral reefs provide the ecological foundation for important fisheries and a tourism-based economy in South Florida that generated an estimated 71,000 jobs and $6 billion of economic activity in 2001 (Johns et al., 2001). Fishing is an important part of this activity and a human stressor on coral reefs.

Florida's reef fisheries are concentrated in South Florida and are complex (Bannerot and Alevizon, 1990; Chiappone and Sluka, 1996). Commercial and sport fisheries target adult reef fishes and spiny lobster for food and sport around bridges and on patch reefs and offshore bank reefs. Fisheries also target live fishes and invertebrates for marine aquaria. Pink shrimp, which are ecologically important as a principal prey item for many reef species, are also economically important and intensively exploited. Adult pink shrimp inhabiting soft and rubble bottoms near coral reefs are targeted by the commercial fishery as a food, and juvenile pink shrimp are targeted as live bait for the recreational fishery in coastal bays and near barrier islands. Finally, pre-spawning subadult pink shrimp are targeted by both food and sport fisheries as they emigrate from coastal bay nursery grounds to offshore spawning grounds.

Total fishing activity reflects Florida's population, which grew tenfold from 1.5 million people in 1930 to 16 million in 2000. In 2000, over five million residents, nearly one-third of Florida's population, lived in the five southern counties adjacent to coral reefs (Palm Beach, Broward, Miami-Dade, Monroe, and Collier Counties). Like residents, recreational fishing (i.e., sport angling and spear fishing) is a popular activity for tourists. Over three million tourists annually visit the Florida Keys alone (Leeworthy and Vanasse, 1999).

Precise data on fishing effort on coral reefs do not exist, but are reflected by statewide fishing statistics. In 2001, for example, an estimated 6.7 million recreational fishers took 28.9 million marine fishing trips in Florida, catching 171.6 million fish, of which 89.5 million (52%) were released or discarded (U.S. DOC, 2003). Although some measures of recreational fishing activity such as the annual number of anglers and fishing trips were unchanged between 1993 and 2002, other measures (e.g., annual totals of fishes caught, released, and landed) may have increased between 1997 and 2002 (Figure 7.6). Additionally, the number of registered recreational boats in five South Florida counties adjacent to coral reefs grew more than 500% between 1964 and 2002, although the number of registered vessels actually used for fishing is unknown (Figure 7.7). In comparison, the number of commercial vessel registrations grew at a much lower rate of about 150% (Figure 7.7). Besides an increased fleet size, 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 (Mace, 1997; Bohnsack and Ault, 1996; Ault et al., 1998, in press).

Fishing can stress coral reefs by removing targeted species, killing non-target species as bycatch, and causing habitat damage. Because fishing is size-selective, concerns exist about ecosystem disruption by removal of ecologically important keystone species, top predators (groupers, snappers, sharks, and jacks), and prey (e.g., shrimps and baitfish). Fishing stress is compounded when combined with other stressors such as pollution and habitat damage. From a fishery perspective, whether stocks decline from fishing or detrimental environmental changes, reducing fishing pressure is an appropriate fishery policy choice (Rosenberg, 2003).

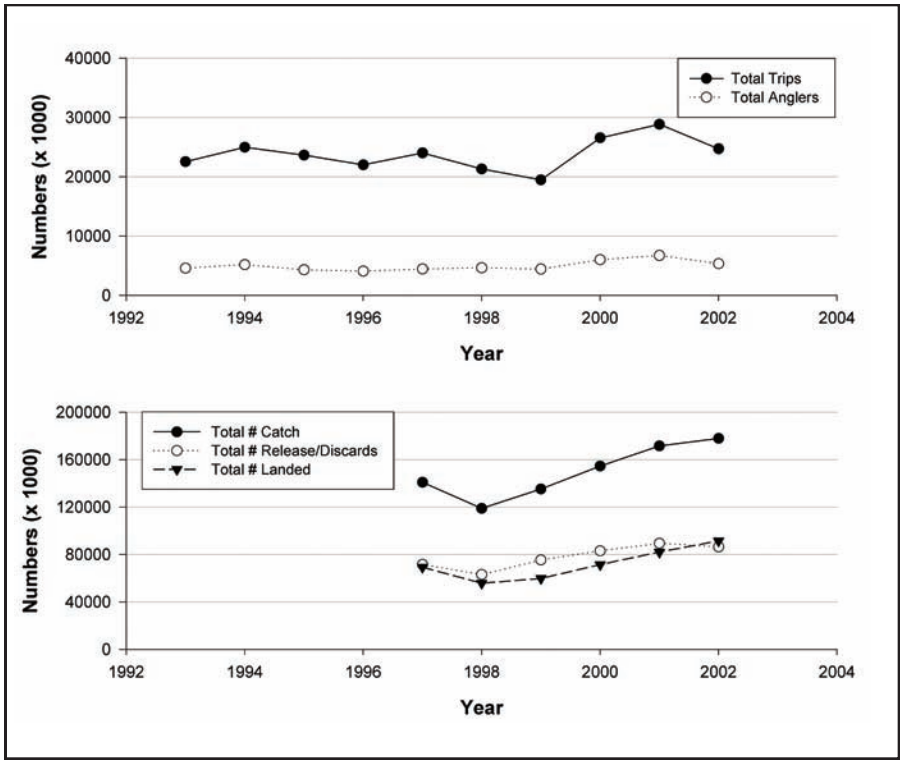

Figure 7.6. Florida total marine recreational fishing trips, angler fishing trips, total catch, and total landings for the period 1993 to 2002 estimated from the MRFSS database. Source: National Marine Fisheries Service SEFSC.

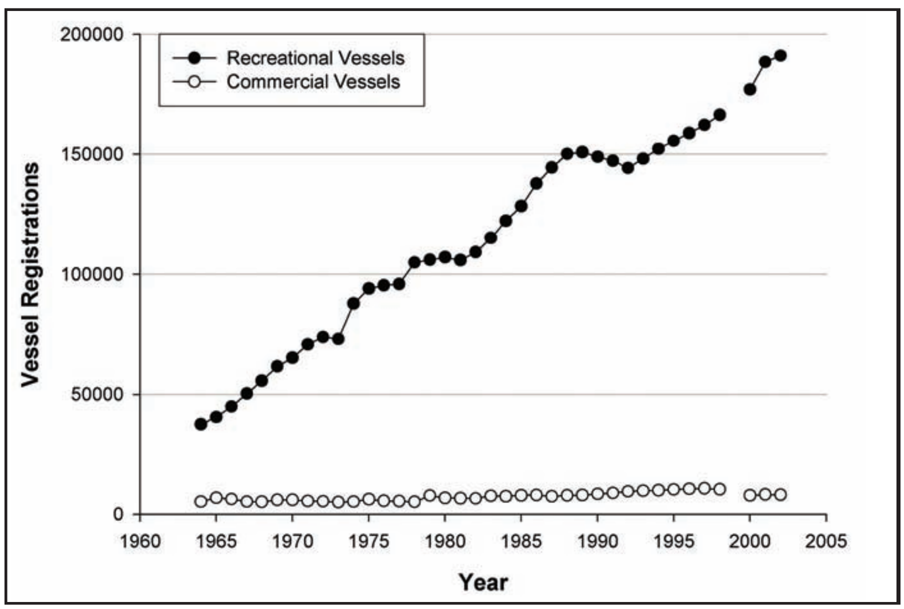

Figure 7.7. Time series of nominal fishing effort for commercial (open circles) and recreational (dark circles) fleets directed at South Florida reef fish from 1964 to 2002. Source: Ault et al. (2001, 2002).

To balance increased fishing pressure, many new fishery regulations have been enacted since the 1980s in Florida state waters by the Florida Fish and Wildlife Conservation Commission (FFWCC; http://www.state.fl.us/gfc/marine) and in Federal waters by the South Atlantic Fishery Management Council (SAFMC, http://www.safmc.net/fishid) and Gulf of Mexico Fishery Management Council (GMFMC, http://www.gulfcouncil.org/about.htm). Their actions include: prohibiting destructive or wasteful fishing gear (e.g., roller trawls, explosives, wire fish traps); requiring reduced bycatch survival (e.g., vessel-holding requirements and limits on number of short lobster used as live bait in lobster traps, escape gaps and release hatches for lobster traps); establishing minimum size and bag limits on a number of reef species landed; establishing seasonal and spatial closures for certain fishing gears (e.g., spears, power heads, lobster diving) and breeding seasons (e.g., for amberjack and black grouper; Bohnsack et al., 1994); limiting or restricting fishing for some species; and limiting entry into certain fisheries. The FKNMS has numerous marine protected areas (MPAs), many of which restrict or eliminate fishing and diving (http://www.fknms. nos.noaa.gov, accessed 2/8/2005). Fisheries for Nassau grouper (*Epinephelus striatus*), goliath grouper (*E. itajara*), queen conch (*Strombus gigas*), and stony corals (Bohnsack et al., 1994) were closed in 1998 and remain closed today.

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.

Ships, Boats, and Groundings

Many ship groundings have occurred on Florida's coral reefs (Table 7.3). Federal and state rules and regulations protect the stony coral (Magnuson-Stevens Fishery Conservation and Management Act, FWC Rule 68B-42.009) and there are specific laws and regulations regarding vessel groundings (16 U.S.C. § 1443 and 1437, FS 253.001 and 253.04). Nevertheless, ship groundings and anchors can damage and destroy corals and other biota. According to the FFWCC's law enforcement records, there are between 500 and 600 vessel groundings reported in the FKNMS annually. In addition, there are many unreported groundings that damage resources. FFWCC data indicate that approximately 12-15% (60 to 90) of groundings have involved injuries to coral reef habitat.

Vessel groundings can be arbitrarily classified as small (<10 m length), medium (10 to 30 m), or large (greater than 30 m). Large vessel groundings often result in immediate and long-term damage. Although the vast ma-

Table 7.3. Summary of vessel groundings in Florida. Source: compiled by staff from FFWCC, NSU, FKNMS, unpublished data.

VESSEL NAME	VESSEL SIZE: MEDIUM, LARGE	YEAR OF INCIDENT	LOCATION	INJURED AREA (M^2)
Capt Allen	M	1973	Middle Sambo, FKNMS	Approximately 125
M/V Lola	L	1976	Looe Key, FKNMS	Approximately 200
M/V Wellwood	L	1984	Molasses, FKNMS	1,282
M/V Mini-Laurel	L	1984	FKNMS	270
M/V Alec Owen Maitland	L	1984	FKNMS	661
M/V Mavro Vetranic	L	1989	Pulaski Shoal, Dry Tortugas	15,800
M/V Elpsis	L	1989	Elbow, FKNMS	2,605
USS Memphis	L	1993	Broward County	1,205
M/V Ms Beholdin	L	1993	Western Sambo, FKNMS	????
M/V Firat	L	1994	Broward County, near Port Everglades	1,000
R/V Columbus Iselin	L	1994	Looe Key, FKNMS	345
M/V Sealand Atlantic	L	1994	Port Everlades entrance, Broward County	Approximately 1000
M/V Igloo Moon	L	1996	Biscayne National Park	1,000
M/V Houston	L	1997	Maryland Shoal, FKMMS	7,107
M/V Hind	L	1998	Broward County, near Port Everglades	1000
M/V Pacific Mako	L	1998	Broward County, near Port Everglades	1000
Lagniappe	M	2001	Key West, FKNMS	35
M/V Diego	L	2001	Tortugas Banks	1,886
M/V Alam Senang	L	2003	Broward County, near Port Everglades	216
M/V Puritan	L	2004	Broward County	100 estimated
M/V Eastwind	L	2004	Broward County, near Port Everglades	11,000 preliminary
Terresa Llyn	M	2002	Dry Tortugas	50 estimated
Captain Bozo	M	2002	Dry Tortugas	50 estimated
Blind Faith	M	2002	Dry Tortugas	50 estimated
Adaro	M	2003		
Connected	M		Western Sambo, FKNMS	
Poetic Justice	M			
High Queen and barge	M	2002	St Lucie inlet	?? minimal
Wave Walker	M	2002	The Rocks, FKNMS	
Jacquelyn L	M		Western Sambo, FKNMS	

jority of grounding incidents are caused by small, privately owned vessels often resulting in minimal resource damage to the resources, the cumulative impacts can be detrimental and long-lasting. Several large- and medium-sized vessel grounding incidents have occurred off the east and south coasts of Florida (Table 7.3). Large vessels often create injuries exceeding 1,000 m^2. The majority of vessel groundings in Florida coral reefs are the result of operator error (poor navigating, lack of local knowledge, and inappropriate charts). Several groundings have occurred because of stormy weather or an inappropriate anchorage. Anchors and chains from large ships can also cause substantial damage, as occurred with the ships M/V *Diego* in 2001 and M/V *Puritan* in 2004. Many of the reported incidents included damage from anchor and chain, as well as from the physical impact of the hull. Damage included crushed, broken, and dislodged organisms (e.g., sponges, *Millepora* spp., octocorals, scleractinian corals, zooanthids, anemones, and bryozoans). Large vessels pulverize the limestone reef substrata creating rubble deposits, fractured structure, and in some cases, canyons or trenches. Ships often attempt to free themselves from the reef by engaging the propeller. The propwash from the propeller mobilizes loose material and may create pits, trenches, and piles of sediment and rubble. Damage caused by a propwash can be more severe than the damage caused by hull contact alone. In Broward County, significant damage to coral reefs was caused by the grounding and subsequent propwash of the nuclear submarine USS *Memphis* (Banks et al., 1999).

The type of impact depends upon grounding circumstances such as storm conditions; the ship's cargo, which governs how much the ship draws; and the length of anchor chain or tug boat line used to tow the vessel off the reef. Many large vessel groundings have occurred near Port Everglades, Broward County (Table 7.3), where ships attempting to anchor or at anchor are driven inshore onto the reef by severe weather. In the Florida Keys, large ship groundings have occurred at Pulaski Shoal, Maryland Shoal, Looe Key, and Molasses, Elbow, and Carysfort reefs. Navigational error was the principal cause, although all of the large ships were equipped with advanced navigating technology, such as, global positioning system (GPS) receivers, radar, radio direction finders, and depth recorders. Often, foreign ships do not have local charts; for example, the *Mavro Vetranic* was found trying to navigate from the eastern Gulf of Mexico into the Straits of Florida with a chart that had coverage of the entire Atlantic Ocean at a scale that did not show local aids to navigation (e.g., lighthouses).

Efforts to reduce the effects of vessel groundings have included installing mooring buoys on highly visited reefs in Monroe, Miami-Dade, and Broward Counties. This has reduced chronic effects from small boat anchoring. The State of Florida and FKNMS have published brochures and made information available on the internet to educate users on the risks and best ways to navigate in coral reef areas. The FKNMS has established large vessel avoidance areas and installed Racon beacons on lighthouses between Dry Tortugas and Key Largo. The beacon transmits a unique signal that is received on active radar receivers identifying the reef lighthouse. There is an active effort to find a better anchorage for Port Everglades. Projected future efforts to reduce groundings include extending vessel avoidance zones, prohibiting the use of Port Everglades anchorage when the wind speed exceeds 25 knots, and enhancing management of the Port Everglades anchorage.

Vessels that run aground because of negligent operation are held responsible by natural resource trustees including the State of Florida, NOAA, and National Park Service (NPS). The nominal responsibility of the shipping company-insurance carrier includes assessment, triage, direct restoration, compensatory restoration (and/or punitive actions), and post-restoration monitoring. Small boat owners are also held responsible for their negligent actions. Scaling for compensation and restoration is based on assessing the injury: defining the spatial extent using biological metrics (abundance and cover of coral) and determining the time necessary for recovery to pre-incident status for both the injured area and the compensatory action. The Habitat Equivalency Analysis method is a useful approach in determining compensation restoration (Fonseca et al., 2000; NOAA, 1997, 2000; Milon and Dodge, 2001).

Restoration at grounding sites has taken a variety of forms in order to enhance recovery (Jaap, 2000). While it is impossible to instantly replace an injured coral reef resource, steps can be taken to promote recovery. The typical scenario is to salvage all detached coral and cache them for subsequent reattachment. It is desirable to remove loose injury-generated rubble to expose the reef foundation (limestone rock) and to eliminate a source of material that could be mobilized and create additional injury in future storm events. If the reef framework is fractured to a significant extent, concrete, native limestone boulders and fiberglass rods may be needed and have been used to stabilize the fractured foundation. After the reef has been cleared of rubble and the foundation made stable, corals are reattached based on microhabitat requirements (e.g., orientation to light and waves). In cases where the reef was rendered flat by severe hull injuries, the topographic relief can be enhanced using native limestone, concrete and prefabricated rock structures. These are often secured with concrete and reinforcement rods.

While there are few detailed studies comparing recovery of restored sites with unrestored injury areas, it is clear that there have been some successes. Coral reattachment has been a useful method. A number of monitoring studies off Broward County have demonstrated very high Scleractinian coral reattachment success (80-95%) (Continental Shelf Associates, 2000; Gilliam et al., 2001, 2003; Thornton et al., 2002). After approximately three years, recruitment of coral (octocoral and scleractinian corals) is very common. For example, there are restored areas off Miami-Dade County where measurements of percent cover, density, and diversity of sessile benthic organisms exceed those at a nearby reference site (Miami-Dade County, 2003).

Marine Debris

Lost and discarded lobster, stone crab, and blue crab traps are a common component of marine debris in Florida. Traps and the associated buoys and ropes are commonly lost during both routine fishing operations and when conflicts occur with other fishing gear and boats. Surveys suggest that, of the 500,000 lobster traps currently in the fishery, 20% of them are lost annually. No surveys have been conducted that estimate the number of lost stone crab and blue crap traps, but fishers report that they replace 20% of the 818,000 stone crab traps used annually, and anecdotal reports suggest that during 1998, 30-50% of the 360,000 blue crab traps were lost. Additional trap losses occur during tropical and severe winter storms. During the Ground Hog Day storm in 1998, approximately 80,000 lobster traps and 22,000 stone crab traps were lost in the Florida Keys. The combined effects of Hurricane Georges and Tropical Storm Mitch later that same year destroyed an estimated 111,000 lobster traps and a few thousand stone crab traps.

Trap debris is distributed in coastal environments and underwater. One shoreline debris removal program conducted during 1999 removed 12,700 kg of plastic trap debris and buoys, filling 1,445 50-gallon plastic bags along five miles of shoreline in the Florida Keys (Figure 7.8). An underwater survey conducted in the Florida Keys during 1993 estimated that there were 2.84 lost or discarded traps per ha. Trap debris on shorelines is a significant source of visual pollution, but probably poses little threat to marine life unless the material is reintroduced to the marine environment. However, submerged trap debris is known to cause the loss of vegetation from beneath the traps and may have more severe effects if moved during storms. The impact of trap debris on coral communities is currently being examined.

Figure 7.8. A mountain of debris removed from the Florida Shoreline during 1999. Photo: T. Matthews.

Aquatic Invasive Species

Fish

Within the United States the number of non-native fishes caught in the wild in Florida is second only to the number caught in California. At least 123 non-native fish species have been caught in Florida. Of these, 56 are established in freshwater habitats and at least four are established in estuaries (FMRI, unpublished data;

USGS, 2003). Fifteen species of non-native tropical reef fishes, mainly angelfishes (*Pomacanthus* spp.), surgeonfishes (*Zebrasoma* spp.), and a serranid (*Chromileptes altivelis*), have been observed in southeastern Florida reefs (Semmens et al., 2004; USGS, 2003), but are not known to be established. The ecological impact of non-native species has been discussed by various authors (Taylor et al., 1984; Carlton and Geller, 1993; Simberloff et al., 1997; Carlton, 2001; Kolar and Lodge, 2002).

The red lionfish (*Pterois volitans*) is the only marine species that appears to have become established in Florida (Whitfield et al., 2002; Ruiz-Carus et al., in press). Six lionfish were freed into Biscayne Bay, Dade County on August 24, 1992, when Hurricane Andrew destroyed a large marine aquarium (Courtenay, 1995). Red lionfish were initially sighted on shallow-water reefs off Palm Beach in October 1992 (Courtenay, 1995). Reports of lionfish were sporadic from 1993 to 2001. In 2002, two voucher specimens were captured off St. Augustine and Jacksonville. Sightings were reported in Nassau, Palm Beach, and Miami-Dade Counties. Gonad histology of the voucher female lionfish showed that most likely it spawned in local waters; the male voucher showed a testis in the mid-maturation class (Ruiz-Carus et al., in press). Red lionfish are now found along the seaward edge of reefs and in lagoons, turbid inshore areas, and harbors (Schultz, 1986; Myers, 1991). In the U.S., red lionfish were also observed at artificial reefs and in waters as deep as 79 m off North and South Carolina (Ruiz-Carus et al., in press). Red lionfish are often found during the day under ledges and crevices but may also hunt small fish, shrimps, and crabs in open water at night (Myers, 1991). The paucity of biological data on red lionfish brings new challenges to managers and researchers.

The red lionfish could pose a threat to Florida's fishers, divers, and wildlife inspectors because it is venomous. Furthermore, potential ecological effects include habitat alteration; water quality degradation; and introduction of diseases and parasites, competition, predation, hybridization, and replacement of native species. As introduction of non-native marine fishes is relatively rare, the effects of such introductions are not well documented.

Both the accidental and purposeful introductions of non-native fishes into Florida waters reflect the rise in Florida's consumption and production of tropical ornamental fishes (Ruiz-Carus et al., in press). It is likely that the number of marine species in the market will increase because of improvements in "mini-reef system" aquaria (Larkin and Degner, 2001), and greater access to remote areas where additional non-native species can be obtained (Larkin, 2003).

Coral

Orange cup coral (*Tubastrea coccinea*) is a solitary or cluster of tubes, usually less than 15 cm high and 2 cm in diameter. Larger clusters may include 50 or more bright orange tubes. The tentacles are orange and often extend outward from the top of the tube capturing food.

Tubastrea coccinea is well known in the Pacific Ocean, Red Sea, and Indian Ocean. The species type was found off of Bora Bora by Lesson in 1829. The earliest report of *T. coccinea* in the Caribbean/western Atlantic is in 1943 from Puerto Rico and Curacao and it was subsequently sited throughout the Caribbean Basin (Jamaica-1955, Cuba-1982, Bahamas-1985, western Gulf of Mexico-1999). In Florida, the preferred habitat is on vertical steel structures (sunken ships and engineering platforms). Tubes are usually facing in the direction of the current. A good example is the sunken vessel, U.S. Coast Guard cutter *Duane* off Key Largo, where the southern facing deck structures are veneered with multiple colonies. *T. coccinea* was reported on the *Duane* in 1999 (J. Sprung, pers. comm.) and that it was well established there by March 2002 (W. Jaap, pers. obs.). In the Pacific, *T. coccinea* is often found in caves with swift water movement, usually below 15 m depth.

The appearance of this coral in Florida indicates that some Indo-Pacific reef fauna can reproduce and survive in the western Atlantic. To date, there are no reports of *T. coccinea* replacing native species and it is only known to settle and grow on steel structures. Monitoring is recommended at selected locations to follow the status and trends in abundance and distribution for *T. coccinea*.

Plants

While non-native fishes and corals may threaten Florida's coral reef, non-native plants pose the greatest risks. The world-wide spread of the algae, *Caulerpa taxifolia*, and its effects in the Mediterranean have been well documented (http://www.pbs.org/wgbh/nova/algae/chronology.html). More recently, *Caulerpa brachypus* (Figure 7.9), native to the Pacific region, has been detected in Florida on nearshore reefs and in the Indian River Lagoon. The species was probably released from saltwater aquaria or from ships' ballast water. In the absence of predators it grows unchecked and can smother corals and seagrass beds rapidly if sufficient nutrients are available (http://www.dep.state.fl.us/southeast/hottopics/caulerpa/cbrachypusalertbulletin.pdf). Recent reports from divers and fishers indicate that the algae has now become so thick on reefs in Palm Beach County, that it is forcing lobsters and fish away. The species has also now been observed 100 km north at Fort Pierce, Florida, and Lapointe and Barile (2003) believe the rapid spread is enhanced by anthropogenic enrichment.

Figure 7.9. The 'green menace', *Caulerpa brachypus*, was introduced to Florida from the Pacific. Anecdotal reports indicate that it is flourishing in Florida and poses a threat to native reef organisms. Photo: L. Nall.

Security Training Activities

Security training activities are not recognized as a major threat to coral reef ecosystems in Florida.

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.

Other

Subsea Engineering Projects: Fiber Optic Cables and Gas Pipelines

In the past decade, multiple fiber optic cables have been installed off Miami-Dade, Broward, and Palm Beach Counties. The nominal construction included horizontal directional drilling from the coast to beyond the first reef terrace. After exiting from the bore hole, the cable was deployed eastward on the surface of the seafloor. During some cable installations, there were "frac-outs" (i.e., when drilling mud escapes from the bore hole through a crack or void in the rock). These incidents were not serious in terms of mortality or morbidity of marine fauna.

In 1999, AT&T Corporation installed four cables off Hollywood Beach in Broward County. Two of the cable deployments resulted in injuries to numerous coral colonies (Table 7.4), and several large barrel sponges (*Xestospongia muta*) were amputated at their bases. The contracting firm paid for direct and compensatory restoration, which included installing mitigation modules (limestone boulders imbedded in a concrete base).

In April 2001, a second cable injury occurred at the ARCOS-I cable deployment in Sunny Isles, Miami-Dade County. Injuries to corals are provided in Table 7.5. The injuries were repaired and compensatory mitigation included installing a boulder field

Table 7.4. Impacts to coral from AT&T incident. Source: PBS&J, 2000.

IMPACT CATEGORY	AMERICAS II CABLE	COLUMBUS III CABLE
Cable overhanging coral	78	56
Cable lying on top of coral	45	63
Cable abrasion injury	12	29
Totals	**135**	**148**

near the cables. Subsequent to the cable installations in 1999-2001, the State of Florida directed cable companies to install all future cables in areas where there are gaps in the reefs to reduce resource injury risks.

Table 7.5. Impacts to coral from ARCOS incident. Source: PBS&J, 2003.

IMPACT CATEGORY	ARCOS NORTH CABLE	ACROS SOUTH CABLE
Cable overhanging coral	67	75
Cable lying on top of coral	34	23
Cable abrasion injury	8	16
Totals	**109**	**114**

A 36-inch diameter gas pipeline (Gulfstream Gas Natural Gas System) was installed from Mobile Bay, Alabama to Port Manatee, Tampa Bay and began operating in May 2002. The pipeline was required to be buried three feet under the seafloor to a water depth of 200 ft; beyond 200 ft, the pipe was positioned on the seafloor. A trench was created with a submarine plow and the pipe was laid in the trench. In multiple areas in and offshore Tampa Bay, the trenching was impeded by dense-hard rock. In cases of partial pipe burial, the contractor used boulders to cover the pipe; in cases where the plow did not penetrate the rock, the contractor fastened the pipe to the rock with metal hardware. Trenching resulted in injuries to coral and other hardbottom resources within Tampa Bay and the Gulf of Mexico. Injuries also occurred from vessel and barge mooring anchors and cables. Injuries within Tampa Bay were compensated by mitigation projects. Two-hundred sponges and octocorals were moved from hardbottom areas in the pipeline corridor to mitigation structures and eight acres of habitat structures (at six mitigation sites) were installed. Each mitigation site provides 1.3-1.4 acres of limestone boulder-pyramids; each site includes 16 to 17 pyramids which are composed of 20 ft long by 24 ft wide, by 3-4 ft high boulders (ENSR International, 2002). Inspections reveal colonization of these structures by algae, sponges, octocorals, blue crabs, stone crabs, and schools of anchovies and spadefish. In the eastern Gulf of Mexico, the pipeline installation disturbed 27 acres of hardbottom, including sponges, octocorals, and stony coral communities. Installation of nine boulder fields and three pre-fabricated module sites mitigated the injuries. Approximately 49 acres of mitigation was provided at the 12 locations seaward of Egmont Key, in depths ranging from 52 to 120 ft (Continental Shelf Associates, 2001; Sea Byte, 2001). Over 400,000 tons of boulders were deployed in discrete fields. The boulders (at least 3 ft in dimension) were deployed in multiple layers to provide refuge. Inspections of boulders and modules revealed colonization by algae, sponges, hydroids, snapper, schools of anchovies, nurse sharks, and goliath grouper.

Additional gas pipeline projects on the east coast of Florida are currently being reviewed for permits. Two proposals from the Calypso-Tractebel and AES Ocean Express have advanced to the point that permitting may occur in 2005. Another pipeline proposed by El Paso is not as far along in the permitting process. These projects propose to install 24-inch diameter pipelines that would originate in the Bahamas, cross the Straits of Florida, and terminate near Port Everglades (Jupiter for El Paso). The draft environmental impact statements for the first two projects proposed the removal of rubber tires deployed in the 1960s as artificial reefs for mitigation of their impacts. These tires have become unbundled, have moved, and are injuring reef resources. Larger corals in known areas of impact will be relocated to non-impacted sites. The pipeline companies propose to avoid injuring reef habitat by drilling under the reefs and connecting the sections of pipe in non-reef areas. There are concerns regarding deployment of construction equipment, “frac-outs” from drilling, possible of a major storm events during drilling, and deployment of pipes in a major boundary current (Gulfstream or Florida Current) in extremely deep water.

Construction of the pipeline projects will involve direct impacts to coral reef habitat from horizontal directional drilling and associated sump berms, trenching in areas where the pipeline will transit from horizontal directional drilling holes, sedimentation and turbidity associated with drilling and trenching, and possible “frac-outs” during drilling. In addition, some pipeline strings have to be laid out and pulled into horizontal directional drilling holes. Some pulling will occur over coral reef habitat, thereby causing injury from the dragging.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

The FKNMS enabling legislation requires a comprehensive water quality status and trends monitoring program with three major components: water chemistry, seagrass, and coral reefs (U.S. DOC, 1996). The protocols and sampling strategies were developed in collaboration with EPA in 1994-95. Water chemistry and seagrass monitoring are conducted by Florida International University; coral reef monitoring is conducted by the FFWCC's Fish and Wildlife Research Institute. The two institutions began collecting data in 1995-96.

The waters of the FKNMS are characterized by complex water circulation patterns, with much of the spatial and temporal variability due to seasonal influences on regional circulation regimes. The Sanctuary is directly influenced by the Florida Current, Gulf of Mexico Loop Current, inshore currents of the southwestern Florida Continental Shelf (Shelf), discharge from the Everglades through the Shark River Slough, and tidal exchange with both Florida Bay and Biscayne Bay (Lee et al., 1994, 2002). Advection from these external sources has significant effects on the physical, chemical, and biological composition of waters within the Sanctuary, as may internal nutrient loading and freshwater runoff from the Keys themselves and episodic upwelling (Leichter et al., 2003).

A spatial framework for water quality management was proposed on the basis of geographical variation of regional circulation patterns (Klein and Orlando, 1994). Quarterly sampling of more than 200 stations in the Sanctuary and on the Shelf, as well as and monthly sampling of 100 stations in Florida Bay, Biscayne Bay, and the mangrove estuaries of the southwestern Florida coast, provide a unique opportunity to explore the spatial variability in water quality measures in South Florida's coastal waters (Figure 7.10). Details on water chemistry sampling strategy, field sampling methods, laboratory analyses, and data processing are available on-line at http://sefrc.fiu.edu/wqmnetwork/ (accessed 1/31/05).

WATER QUALITY

Methods

Several variables were measured *in situ* and from grab samples at 54 fixed stations within the Sanctuary boundary beginning in March 1995 (Figure 7.10). Depth profiles of temperature, salinity, dissolved oxygen (DO), photosynthetically active radiation (PAR), *in situ* chlorophyll *a* (CHL*a*) specific fluorescence, optical backscatterance turbidity, depth, and density were measured by conductivity-temperature-depth (CTD) casts using a Seabird SBE 19 instrument (Table 7.6). Vertical light attenuation (k_d, per meter) was calculated at 0.5 m intervals from PAR and depth (Kirk, 1994) and averaged over the depth of each station. Where it was too shallow to use a CTD, surface salinity and temperature were measured using a combined salinity-conductivity-temperature probe. DO was measured with an oxygen electrode corrected for salinity and temperature. PAR was measured with a Li-Cor irradiance meter. The extent of water stratification was calculated as the difference between surface and bottom density ($\Delta\delta_t$), such that positive values denoted greater densities

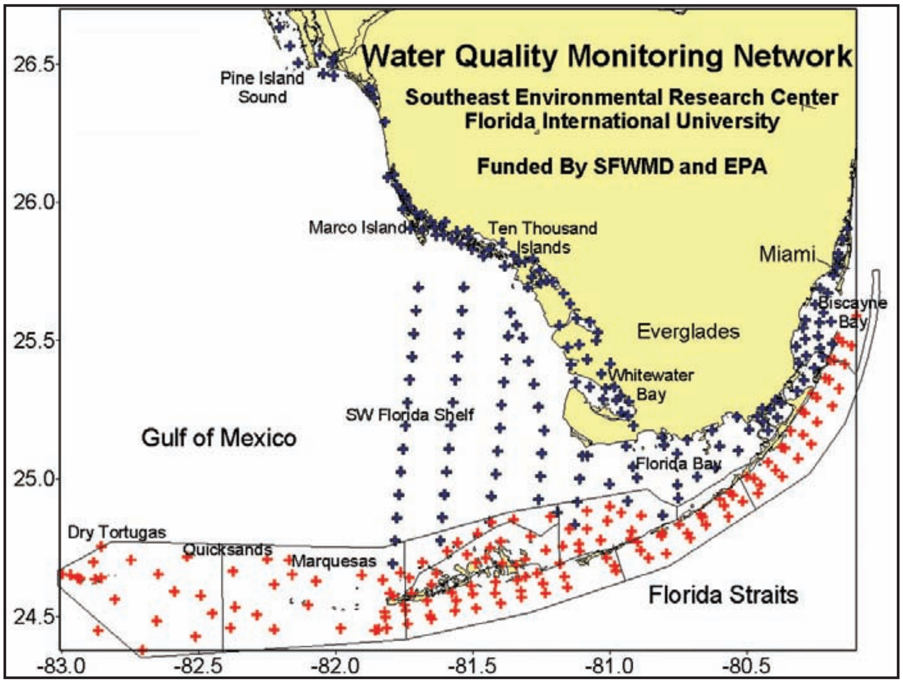

Figure 7.10. The Southeast Environmental Research Center (SERC) Water Quality Monitoring Network showing the distribution of fixed sampling stations (+) within the Florida Keys National Marine Sanctuary (red stations) and Florida Bay, Biscayne Bay, Whitewater Bay, Ten Thousand Islands, and Southwest Florida Shelf (blue stations). Source: Boyer and Jones, 2003.

of bottom water relative to the surface and negative values indicated the opposite. A value of $\Delta\delta_t$ >1 indicated weak stratification, whereas $\Delta\delta_t$ >2 meant strong water stratification.

Water samples were collected from approximately 0.25 m below the surface and at approximately 1 m from the bottom. Unfiltered water samples were analyzed for total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), silicate ($Si(OH)_4$), alkaline phosphatase activity (APA), and turbidity. Fluorescences at initial and after two-hour incubation were measured using a spectrofluorometer (Jones, 1996). Filtrates were analyzed for nitrate+nitrite (NO_x^-), nitrite (NO_2^-), ammonium (NH_4^+), and soluble reactive phosphorus (SRP).

Several parameters were not measured directly. Nitrate (NO_3^-) was calculated as NO_x^- - NO_2^-, dissolved inorganic nitrogen (DIN) was determined as NO_x^- + NH_4^+, and total organic nitrogen (TON) was defined as TN - DIN. DO saturation in the water column (DO_{sat}) was calculated using the equations of Garcia and Gordon (1992). 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 Jones, 2003). 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.

Summary statistics for all water quality variables from all 29 sampling events through September 2002 are shown as median, minimum, maximum, and number of sample stations (Table 7.6). Overall, the region was warm and euhaline with a median temperature of 27.1°C and salinity of 36.2 parts per thousand (ppt); DO_{sat} was relatively high at 90.1%. On this coarse scale, the Sanctuary exhibited very good water quality with median NO_3^-, NH_4^+, and TP concentrations of 0.09, 0.30, and 0.20 µM, respectively. NH_4^+ was the dominant DIN species in almost all of the samples (~70%). However, DIN comprised a small fraction (4%) of the TN pool with TON

Table 7.6. Median, minimum (Min.), and maximum (Max.) values and the number of sample stations (n) for water quality variables measured in the Florida Keys National Marine Sanctuary between March 1995 and September 2002. Source: Boyer and Jones, 2003.

VARIABLE	DEPTH	MEDIAN	MIN.	MAX.	n
Nitrate (µM)	Surface	0.087	0	5.902	4386
	Bottom	0.08	0	5.01	2675
Nitrite (µM)	Surface	0.043	0	0.71	4396
	Bottom	0.038	0	1.732	2682
Ammonium (µM)	Surface	0.299	0	10.32	4395
	Bottom	0.268	0	3.876	2680
Total Nitrogen (µM)	Surface	10.83	1.707	211.1	4391
	Bottom	9.036	1.482	152.23	2661
Total Organic Nitrogen (µM)	Surface	10.261	0.389	210.78	4372
	Bottom	8.445	0	151.91	2641
Total Phosphorus (µM)	Surface	0.198	0	1.777	4394
	Bottom	0.185	0	1.497	2663
Soluble Reactive Phosphorus (µM)	Surface	0.013	0	0.297	4383
	Bottom	0.013	0	0.39	2674
Alkaline Phosphatase Activity (µM h^{-1})	Surface	0.06	0	5.616	4232
	Bottom	0.048	0	0.491	2520
Chlorophyll *a* (µg l^{-1})	Surface	0.261	0.01	15.239	4394
Total Organic Carbon (µM)	Surface	199.69	83.77	1653.5	4393
	Bottom	171.6	89.38	883.1	2669
Silicate (µM)	Surface	0.701	0	127.11	4090
	Bottom	0.455	0	30.195	2491
Turbidity (NTU)	Surface	0.62	0	37	4349
	Bottom	0.52	0	16.9	2700
Salinity	Surface	36.2	26.7	40.9	4315
	Bottom	36.2	27.7	40.9	4287
Temperature (ºC)	Surface	27.1	15.1	39.6	4322
	Bottom	26.6	15.1	36.8	4294
Vertical Light Attenuation Coefficient k_d (m^{-1})		0.23	0.003	3.41	3050
Dissolved Oxygen saturation (%)	Surface	90.1	31.2	191.6	4286
	Bottom	89.9	19.3	207	4240
Water Stratification (surface density - bottom density, $\Delta\delta_t$)		0.007	-4.42	6.64	4269

making up the bulk (median 10.3 µM). SRP concentrations were very low (median 0.013 µM) and comprised only 6% of the TP pool. CHL*a* concentrations were also very low overall (0.26 µg/L), but ranged from 0.01 to 15.2 µg/L. TOC was 199.7, a value higher than open-ocean levels but consistent with coastal areas. Median turbidity was low (0.6 nephelometric turbidity units, or NTUs) as reflected in a low k_d (0.23/m). This resulted in a median photic depth of approximately 22 m, which was within 1% of incident PAR. Molar ratios of nitrogen (N) to phosphorous (P) suggested that was P was limited in the water column (median TN:TP = 57), but observed ratios of N to P could have resulted because TN may not be biologically available.

Principal component analysis identified five composite variables (hereafter refered to PC1, PC2, etc.) that accounted for 63.2% of the total variance. PC1 had high factor loadings for NO_3^-, NO_2^-, NH_4^+, and SRP and was named the inorganic nutrient component. PC2 included TP, APA, CHL*a*, and turbidity and was designated as the phytoplankton component. The covariance of TP with CHL*a* implies that, in many areas, phytoplankton biomass may be limited by phosphorus availability. This is contrary to much of the literature on the subject, which usually ascribes nitrogen as the limiting factor for phytoplankton production in coastal oceans. TON and TOC were included in PC3 as the terrestrial organic component. Temperature and DO were inversely related in PC4. Finally, PC5 included salinity and TP, implying a source of TP from marine waters.

Spatial distributions of the mean factor score for each station indicated that water quality varied over the study area (Figure 7.11). The inorganic nutrient component had two peaks in the Backcountry, and along the northern side (bayside) of the Middle Keys (Figure 7.11). The phytoplankton component described a north to south gradient in the Backcountry and Sluiceway that extended west across the northern Marquesas. The terrestrial organic component was highest in eastern Sluiceway extending into the Backcountry and was also distributed as a gradient away from land on the Atlantic side (oceanside) of the Keys. Temperature and DO showed a distribution heavily loaded in the oceanside. Finally, the salinity/TP component showed lower loadings in the nearshore Upper Keys and bayside Sluiceway extending through most Atlantic sites of the Middle and Lower Keys.

Cluster analysis separated sampling sites (n=150) into eight clusters, with most stations grouped within clusters 1, 3, 5, 6, 7, and 8 (Figure 7.12). Statistically significant differences between clusters indicated a nutrient gradient throughout the Sanctuary (highest to lowest concentrations: clusters 7 & 8 > 1 > 5 > 6 > 3). Cluster 7 was composed primarily of stations located inside the Backcountry,

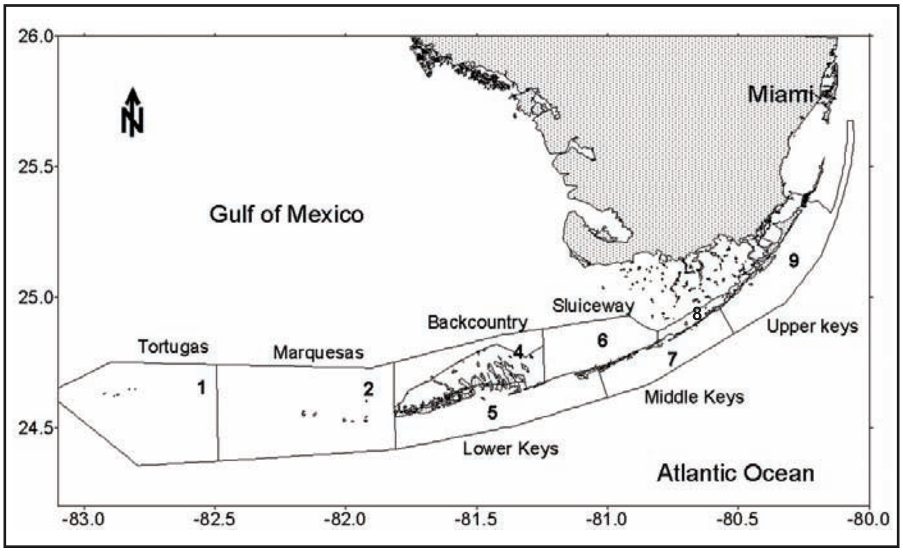

Figure 7.11. Map of South Florida showing the boundary of the Florida Keys National Marine Sanctuary and geographic segments (names and numbers) used for site selection during routine water quality sampling for the period 1995 to 2003. Source: Boyer and Jones, 2003.

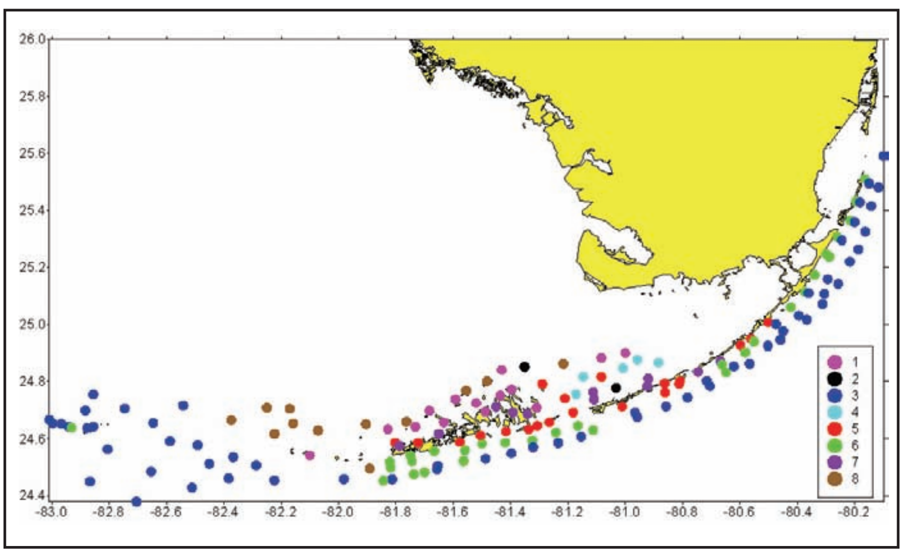

Figure 7.12. Map of sample stations forming distinct water quality groups represented by colored dots. Station groups were identified through objective classification analysis. Source: Boyer and Jones, 2003.

bayside Middle Keys, and inshore sites off Lower Matecumbe Key. This group was highest in inorganic nutrients, especially NO_3^-, TOC, and TON. In the shallow Backcountry sites benthic flux of nutrients might be very important, whereas elevated DIN at inshore Lower Matecumbe sites may be the result of anthropogenic loading. Cluster 8 included the northernmost sites in the Sluiceway, Backcountry, and Marquesas, which had the highest TP, CHL*a*, and turbidity, but was low in inorganic nutrients, DON, and DOC. Water quality in this cluster probably was driven primarily by Shelf circulation patterns.

Cluster 1 was composed of two sites in the northern Sluiceway and 12 sites in the northern Backcountry extending out to the Marquesas (Figure 7.12). This group was high in TP, CHL*a*, and turbidity. The main distinction between Clusters 1 and 8 was that Cluster 8 was higher in CHL*a* and lower in TOC. These clusters may be viewed as a gradient of high-TP Shelf water being attenuated by uptake of nutrients within the Backcountry and/or mixing with Atlantic Ocean waters.

Clusters 5, 6, and 3 may be interpreted as representing an onshore-offshore nutrient gradient (Figure 7.12). Cluster 5 included most of the inshore sites of the Keys, excluding the northernmost and southernmost ones. They were elevated in DIN relative to Hawk Channel and reef tract sites. Cluster 6 was made up of sites in Hawk Channel of the Lower Keys and alongshore sites in the Upper Keys. This group was slightly lower in nutrients than Cluster 5. Cluster 3 was made up of outer reef tract and Tortugas stations. These sites had the lowest nutrients, CHL*a*, turbidity, and TOC in the Sanctuary. A clear gradient of elevated DIN, TP, TOC, and turbidity from alongshore to offshore was observed in the Keys, with the Upper Keys being lower than the Middle and Lower Keys. The elevated DIN in the nearshore zone of the Keys was not observed in the nearly uninhabited Tortugas, indicating an anthropogenic source. No significant onshore-offshore gradient was observed for CHL*a*.

The highest concentrations of CHL*a* were observed on the southwestern Shelf (Figure 7.13), with a strong decreasing gradient toward the Marquesas and Tortugas. This pattern was likely caused by higher TP concentrations on the Shelf because of southward advection of water along the mainland coast. Most parameters were relatively consistent from year to year, with some seasonal excursions. The exceptions were statistically significant increases in TP and decreases in DO and TOC throughout the region (Figure 7.14).

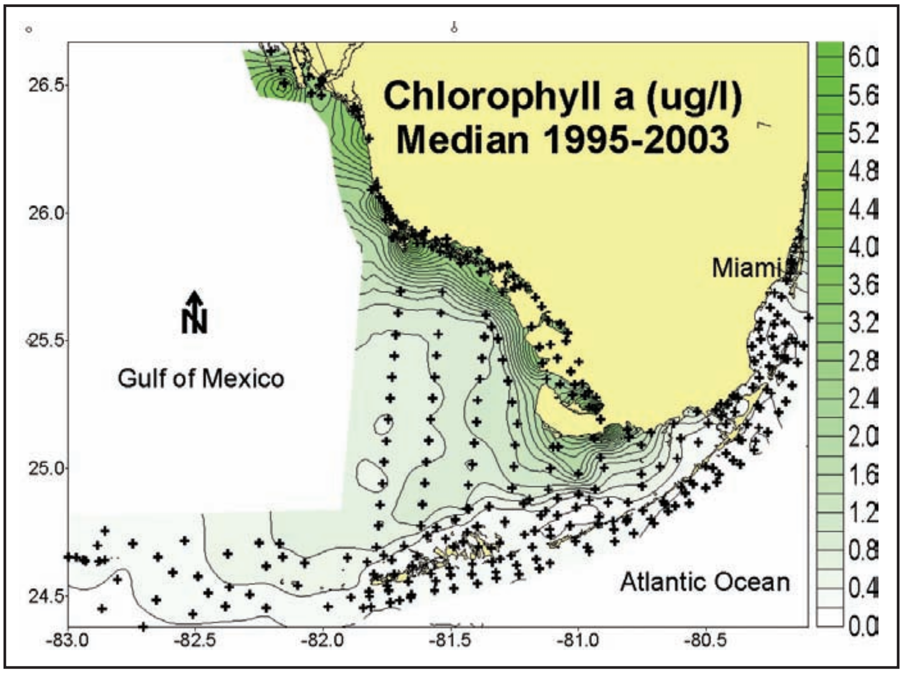

Figure 7.13. Distribution of median concentrations of Chlorophyll *a* in Florida's coastal waters for the period 1995 to 2003. Sampling stations are indicated with a + symbol. Source: Boyer and Jones, 2003.

The local trends described in this study may occur across the whole region, although less pronounced. This spatial autocorrelation in water quality is an inherent property of highly interconnected systems such as coastal and estuarine ecosystems driven by similar hydrological and climatological forcings. Large changes have occurred in Sanctuary water quality over time, and some sustained monotonic trends have been observed (Figure 7.14). However, trend analysis is limited to the window of observation; trends may change, or even reverse, with additional data collection.

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 network (which includes Florida Bay, Whitewater Bay, Biscayne Bay, Ten Thousand Islands, and Southwest Florida Shelf) are available at http://serc.fiu.edu/wqmnetwork (Accessed, 1/31/2005).

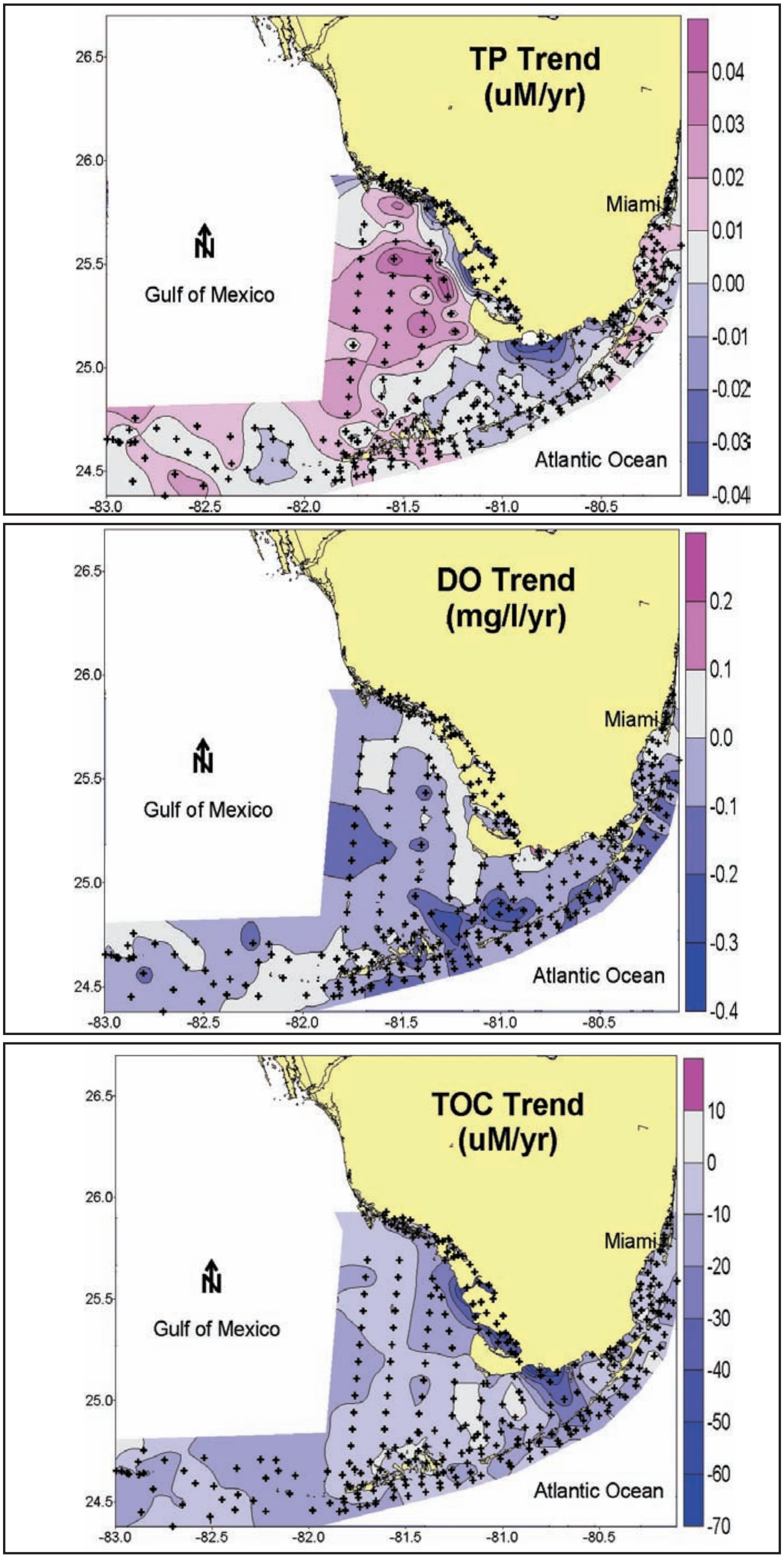

Figure 7.14. Distribution of significant increases in total phosphorus concentrations (top panel) and decreases in dissolved oxygen (middle panel) and total organic carbon (bottom panel). Sampling stations are indicated with a + symbol. Source: Boyer and Jones, 2003

BENTHIC HABITATS

The Coral Reef Evaluation and Monitoring Project

Methods

The FFWCC's Coral Reef Evaluation and Monitoring Project (CREMP) tracks the status and trends of stony corals and selected benthic biota at 53 stations across the Florida Reef Tract from Palm Beach through the Dry Tortugas. The project annually samples at 43 permanent sites in the Florida Keys and Dry Tortugas and 10 sites off the Southeast Florida coast in Palm Beach, Broward, and Miami-Dade Counties. Habitat types include hardbottom, patch reef, shallow offshore, and deep offshore communities. Within stations, sampling consists of a station species inventory (SSI), video transects, and a bioeroding sponge survey. Diseased coral surveys, stony coral abundance surveys, and temperature surveys are also conducted at selected sites. Details on sampling strategy, field methods, and data processing and analyses may be accessed at http://www.floridamarine.org/corals (Accessed 2/8/05).

Results and Discussion

The inventory of coral species richness within FKNMS from 1996 through 2003 exhibited a trend of general decline in stony coral species richness in all reef types and geographic areas (Upper, Middle, and Lower Keys). The number of species observed declined at 74 stations (70%), increased at 21 stations (20%), and remained stable at 10 stations (10%). More coral species were seen at deep reef and patch reef stations than in shallow reef and hardbottom stations (Table 7.7).

Table 7.7. Change in coral species richness among benthic habitats and regions of the Florida Keys and Dry Tortugas between 1996 and 2003. Source: Jaap et al., 2003.

CATEGORY	LOST TAXA		GAINED TAXA		UNCHANGED	
	#	%	#	%	#	%
All stations	74	70	21	20	10	10
Hard bottom	6	55	3	27	2	18
Patch Reef	29	72	3	11	5	14
Shallow offshore	28	72	10	26	1	3
Deep offshore	26	73	5	15	2	6
Upper Keys	23	77	2	7	5	17
Middle Keys	20	69	7	24	2	7
Lower Keys	31	67	12	26	3	7
Dry Tortugas*	9	75	3	25	0	0

*Database for Tortugas is 1999 – 2002. (gains + unchanged)

The number of stations where *Acropora cervicornis* and *Scolymia lacera* were present decreased significantly (P <0.05) while *Copolphyllia natans, Madracis mirabilis, Porites porites, Siderastrea radians, Mycetophyllia ferox,* and *M. lamarkiana* showed decreases (P <0.1). Only *Siderastrea siderea* was observed at a significantly greater number of stations in 2001-2002 than in previous years.

There were trends showing increases in the number of stations where coral disease occurred, number of different types of disease, and number of coral species infected with disease. In 1996, diseased corals were seen at 20 stations, compared with 95 stations in 2003. Black band disease (BBD; Rützler and Santavy, 1983) was least common of the conditions monitored; the incidence of BBD was slightly higher in 1998 and has wavered at low levels in subsequent years. *Colpophyllia natans, Montastraea annularis, Montastraea cavernosa* and *Siderastrea siderea* were the species most infected by BBD. In 1996, white band disease (WBD) was recorded at five stations; in 2002 it was present at 90 stations. WBD in *Agaricia agaricites* was not seen at any stations in 1996, but was seen at 33 stations in 2002. *Montastraea annularis* complex followed a similar pattern with no reports in 1996, but corals at 32 stations showed infection in 2002. Purple spot on *Siderastrea siderea* was also reported. Fourteen species exhibited an increase in diseases: *Agaricia agaricites, Colpophyllia natans, Dichocoenia stokesii, Eusmila fastigiata, Favia fragum, Meandrina meandrites, Millepora alcicornis, Millepora complanata, Montastraea cavernosa, Montastraea annularis* complex*, Porites astreoides, P. porites, S. siderea,* and *Stephanocenia michelinii*.

Coral cover exhibited a significant decline for the period 1996-1999; there was no significant change from 1999- 2003 (Figure 7.15). These changes were most likely related to bleaching episodes in 1997 and 1998 and hurricanes in 1998 and 1999. The areas most influenced by these disturbances were shallow offshore sites. During bleaching events, temperatures were high enough to cause expulsion of zooxanthellae, thereby discoloring many of the zooanthids, fire coral, stony corals, and some octocorals such as *Biareum* spp. The organisms that exhibited the most bleaching were *M. complanata* and *Palythoa mammillosa*. These are sentinel species; they bleach at a slightly lower threshold than many of the other corals. *M. complanata* cover decline was greatest from 1998 to 1999 and has not recovered since then (Table 7.8). The percent cover and frequency of occurrence of corals improved slightly after 2001. The bleaching event in 1997 may have stressed *M. complanata*, and a second exposure to hypothermia in 1998 may have been sufficient to reduce the population drastically.

The golden sea mat (*Palythoa mammillosa*) is conspicuous in shallow reefs. The CREMP analysis pooled all zooanthids (*Zoanthus* spp., *Palythoa* spp., *Ricordia* spp.) into a single category. Virtually all zoanthids observed in the images were *P. mammillosa*. Unlike the fire coral, (*M. complanata*), *P. mammillosa* showed little change in cover after the bleaching disturbance (Table 7.9). A slight reduction in the mean percent cover of *P. mammillosa* occurred between 1997 and 1998, although population levels equaled or exceeded the pre-bleaching period in 2000 and subsequent years.

Hurricane Georges crossed the Straits of Florida near Key West on September 25, 1998. Sombrero Key C-MAN buoy recorded a maximum sustained wind of 82 knots with a peak gust to 92 knots at 1500 Universal Time on September 25 (Table 7.10). Hurricane Georges' greatest influence on coral reef communities was between Sombrero Key and Dry Tortugas. The hurricane's impact was evidenced by the change in *Acropora palmata* cover, which decreased in range, mean, and frequency of occurrence after Hurricane Georges (Table 7.11). Sampling occurred before the hurricane struck in 1998, thus the major decline is most noticeable in 1999 and subsequent years. *A. palmata* exhibited the highest pre-hurricane cover at Western Sambo station two: 15.28% in 1996 and 16.34% in 1997 (Table 7.11). Figure 7.16 provides evidence of the coral cover loss attributed to Hurricane Georges.

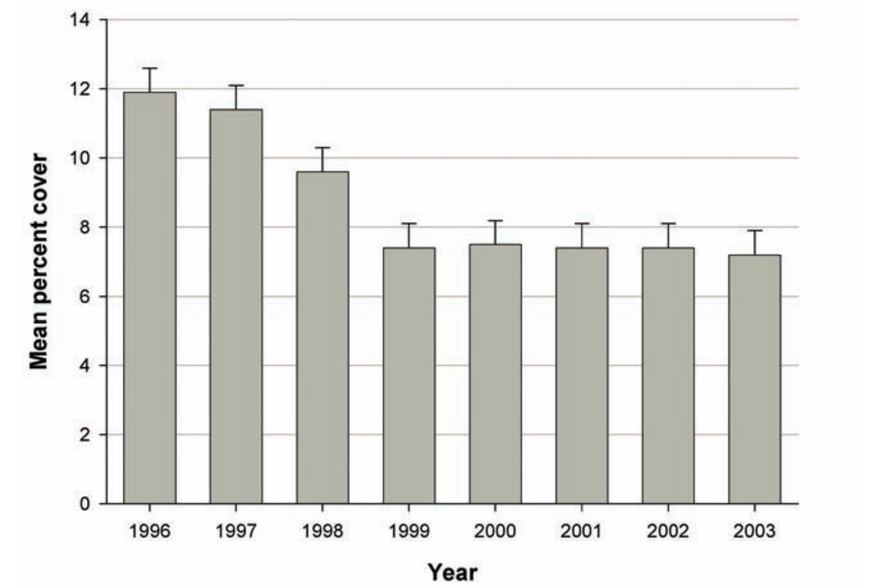

Figure 7.15. Mean percent live coral cover in the Florida Keys National Marine Sanctuary between 1996 and 2003. Source: Jaap et al., 2003.

Table 7.8. Descriptive statistics for annual percent cover of *Millepora complanata* in the Florida Keys National Marine Sanctuary between 1996 and 2002. Source: Jaap et al., 2003.

YEAR	1996	1997	1998	1999	2000	2001	2002
Range	0-15.71	0-17.33	0-16.44	0-1.88	0-1.19	0-0.85	0-0.49
Mean	2.55	2.23	1.56	0.19	0.13	0.09	0.11
Std.dev.	4.54	4.05	3.25	0.37	0.28	0.18	0.17
Freq.	0.85	0.85	0.72	0.48	0.33	0.41	0.46

Table 7.9. Descriptive statistics for annual percent cover of *Palythoa mammillosa* in the Florida Keys National Marine Sanctuary between 1996 and 2002. Source: Jaap et al., 2003.

YEAR	1996	1997	1998	1999	2000	2001	2002
Range	0-25.54	0-24.69	0-20.01	0-22.48	0-24.45	0-21.54	0-25.39
Mean	4.36	4.97	4.4	4.25	4.61	4.48	5.3
Std.dev.	5.4	5.74	4.95	5.11	5.67	5.6	6.32
Freq.	0.92	0.97	0.92	0.94	0.92	0.92	0.89

Table 7.10. Data on conditions during Hurricane Georges at C-MAN Stations in the Florida Keys, October, 1999. Source: NOAA National Hurricane Center, http://www.nhc.noaa.gov/abouttafb.shtml, Accessed: 2/14/2004.

LOCATION	PRESS. (mb)	DATE/TIME (UTC)	SUSTAINED WIND (kts)	PEAK GUST (kts)	DATE/ TIME (UTC)
Lake Worth, FL	1010.0	25/1100	30	35	25/1400
Fowey Rocks, FL	1006.3	25/1000	45	52	25/1000
Molasses Reef, FL	1003.1	25/0800	46	53	25/1400
Long Key, FL	1000.0	25/1000	47	58	25/1400
Sombrero Key, FL	994.5	25/1300	81	92	25/1500
Sand Key, FL	990.5	25/1300	56	71	25/1400
Dry Tortugas, FL	976.3	25/2000	59	68	26/0000

The National Hurricane Center reported that Tropical Storm Irene reached hurricane status over the Florida Straits on October 14, 1999. The center moved over Key West on October 15 (Table 7.12). Most of the hurricane force winds were confined to the east of Irene's center over the lower to middle Florida Keys. Irene made its fourth landfall near Cape Sable, Florida and then moved across southeast Florida before crossing the Keys, into the Everglades. Its sustained and peak wind gusts were less than those of Hurricane Georges (Table 7.10). The second hurricane in 13 months disturbed offshore shallow reefs, but since Hurricane Georges had already reduced populations of *A. palmata* and other organisms, Hurricane Irene's influence was somewhat muted.

Table 7.11. Descriptive statistics for annual percent cover of *Acropora palmata* in the Florida Keys National Marine Sanctuary between 1996 and 2002. Source: Jaap et al., 2003.

YEAR	1996	1997	1998	1999	2000	2001	2002
Range	0-15.28	0-16.34	0-9.96	0-3.40	0-2.72	0-2.44	0-4.88
Mean	2.97	2.91	1.79	0.4	0.33	0.27	0.4
Std.dev.	4.6	4.55	3.2	0.9	0.73	0.58	0.98
Freq.	0.44	0.44	0.38	0.28	0.3	0.28	0.28

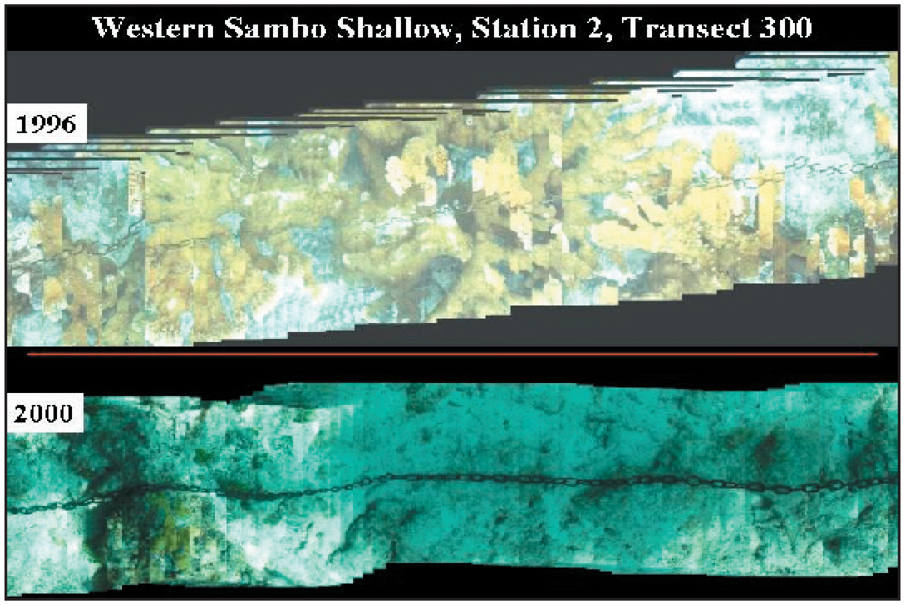

Figure 7.16. Loss of *Acropora palmata* along a video transect at Western Sambo, Florida Keys between 1996 and 2000. Source: Jaap et al., 2003.

Table 7.12. Data on conditions during Hurricane Irene at C-MAN Stations in the Florida Keys, October, 1999. Source: NOAA National Hurricane Center, http://www.nhc.noaa.gov/abouttafb.shtml, Accessed: 2/14/2004.

LOCATION	PRESS. (mb)	DATE/ TIME (UTC)	SUSTAINED WIND (kts)	PEAK GUST (kts)	DATE/ TIME (UTC)
Sombrero Key C-MAN	990.5	15/1700	57	69	15/1530
Molasses Reef C-MAN	991.5	15/2100	53	64	15/2020
Long Key C-MAN	988.7	15/2000	50	61	15/2000
Sand Key C-MAN	987.0	15/1200	43	57	15/0610
Dry Tortugas C-MAN			41	51	15/0850
Key West Intl. Airport	987.6	15/1010	38	47	15/0518

Frequency and Distribution of Coral Diseases

Methods

A broad-scale survey to determine the frequency and distribution of coral disease in the Florida Keys was conducted in August 2000 and incorporated 30 sites from Key Biscayne to the Dry Tortugas. Sites were located in Biscayne National Park, FKNMS, New Grounds, and the Dry Tortugas National Park. A sampling protocol similiar to those used in EPA's Environmental Monitoring and Assessment Program was used to select site locations (Summers et al., 1995; Santavy et al., 2001). The probabilistic sampling design was generated and implemented to estimate the baseline condition of reef corals to compare with future assessments. The survey will be repeated in August 2005.

The study produced unbiased estimates of coral condition with a quantifiable level of uncertainty for the distribution and frequency of coral diseases in the Florida Keys. The distribution of coral disease was assessed as present or absent for each site. The frequency of coral disease was the percentage of diseased coral from each site. The area represented by the study was 41 km^2 of the South Florida Keys Tract. The reef areas of the Florida Keys (Upper, Middle, and Lower Keys; New Grounds; and Dry Tortugas) that contained hard coral bottom were demarcated based on benthic habitat maps of the Florida Keys (FMRI, 1998). Habitat boundaries were redefined by experts to include areas known to have living corals and to eliminate areas that contained only dead or geological reef structure. The design was developed in three steps: (1) regional stratification, (2) overlay of a hexagonal grid on the sample frame, and (3) random selection of multiple sites within grid cells (Summers et al., 1995; Santavy et al., 2005).

Results and Discussion

The areal estimates of coral disease generated by the 2000 survey indicated that at least one coral colony affected by active disease was observed in 85% ± 9 (95% confidence intervals) of the area sampled. Coral disease was widely dispersed throughout the Florida Keys Reef Tract and did not seem to be confined to a particular region. While the presence or distribution of disease was widespread, the proportion of colonies affected by disease or disease prevalence at any particular location was significantly less. The maximum percent of coral colonies affected with disease or maximum prevalence of coral disease in South Florida at any one site during August 2000 was 13%, with 2.2% ± 4 (97 ha) of the sampling area containing this maximum level of coral disease (Figure 7.17). Approximately 15% ± 9 (662 ha) of the area sampled contained no coral disease, whereas 31% ± 14 (1,369 ha) of the area had between 0.4%- 2.2% of the colonies affected by coral disease. Approximately 28% ± 15 (1,236 ha) of the area had greater than 2% and no more than 4% of colonies affected by disease. Finally, 24% ± 4 (1,060 ha) of the sampled area had between 4% and 9% frequency of coral disease. By establishing this baseline, future surveys can examine changes and trends in the spatial and temporal distribution and frequency of coral disease in South Florida (Santavy et al., 2005). This approach will allow the condition of reefs to be classified generally from excellent to degraded, to better communicate their status to the public and policy makers.

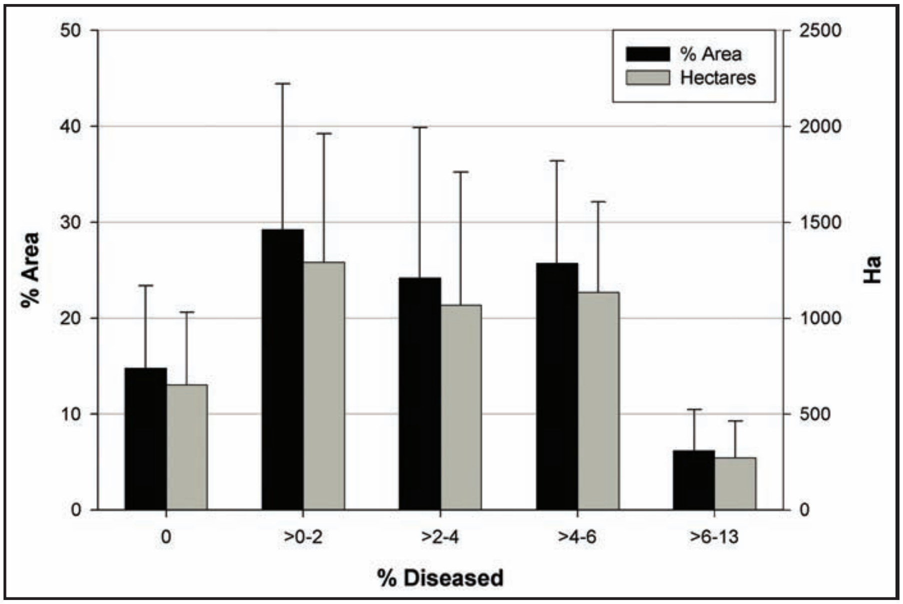

Figure 7.17. Frequency of coral disease or percent area having 0-13% of colonies affected by coral diseases in South Florida Keys Tract. Error bars represent 95% confidence levels. Source: Santavy et al., 2005.

Regional Coral Disease Assessments

Methods

Coral disease prevalence was compared between different geographical regions in the Dry Tortugas, New Grounds, Key West region, Lower Keys, Middle Keys, and Upper Keys from 1998 to 2002 (Figure 7.18). All surveys were conducted using a radial arc transect method developed for the coral disease surveys (Santavy et al., 2001). If the location had sufficient coral coverage (>5%), a permanent installation was made and the site was surveyed. Only the 8-10 m segment of the radial arc transect (113 m^2) was necessary to estimate coral disease (Mueller et al., 1998; Santavy et al., 1999a, 2001). Twenty-two species of scleractinian corals and gorgonian sea fans were surveyed and only colonies greater than 10 cm were counted. *M. annularis, M. faveolata,* and *M. franksii*, the three species of coral contained within the Montastraea annularis complex (Weil and Knowlton, 1994) were combined as a single taxon, *M. annularis*, for data analysis. Two gorgonian sea fan species were combined as *Gorgonia* spp.

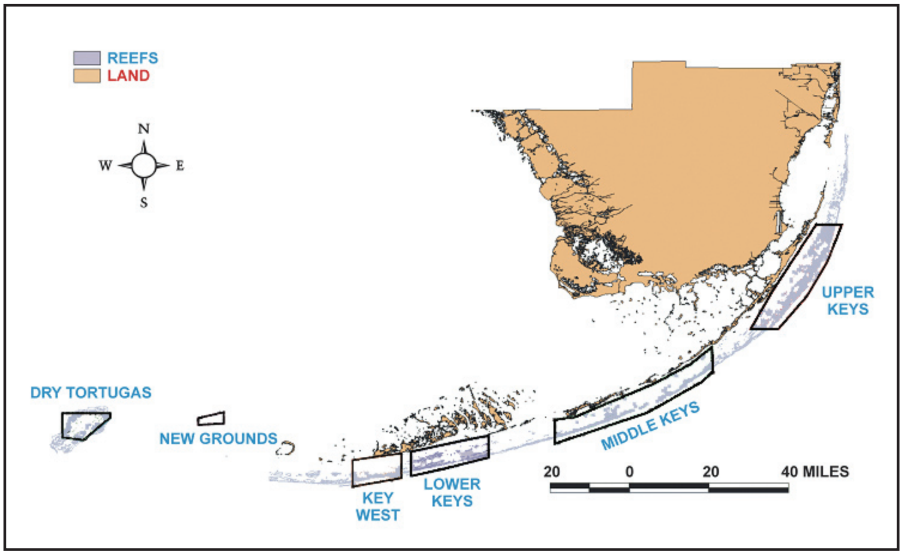

Figure 7.18. Map of the coral disease assessment regions, in which all the sites were contained in this study, including areas in Dry Tortugas National Park, New Grounds, Key West, Lower Keys, Middle Keys, Upper Keys and Biscayne National Park. Source: Santavy et al., 2005.

Only coral colonies containing active disease lesions were enumerated.

The diseases consistently assessed are listed in Table 7.13. Signs used to distinguish coral diseases were obtained from published literature (McCarty and Peters, 1998; Patterson et al., 2002; Santavy and Peters, 1997; Santavy et al., 1999a,b, 2001). No distinction was made between white plague type 1 and 2 (Dustan,1977; Richardson et al.,1998a,b). Additionally, a combination of 13 disease conditions obtained from published literature was used to identify seafan disease (Smith et al., 1996; Nagelkerken et al., 1997a, b; Santavy et al., 2001; Kim and Harvell, 2002).

Table 7.13. Diseases assessed in surveys with corresponding abbreviations and references detailing the signs used in assessing condition. Source: Santavy et al., 2005.

DISEASE NAME	DISEASE ABBREVIATION	SPECIES AFFECTED IN TROPICAL WESTERN ATLANTIC	REFERENCES
Sea Fan Disease	SD	*Gorgonia* spp.	Nagelkerken et al., 1997a, b; Smith et al., 1996.
Black Band Disease	BB	*Diploria strigosa, D. labyrinthiformis, Colpophyllia natans, Montastraea cavernosa, M. annularis, M. frankii, M. faveolata, Siderastrea siderea, Gorgonia* spp.	Antonius,1981; Rützler et al.,1983; Rützler & Santavy, 1983.
Dark Spot Disease	DS	*C. natans, M. annularis* (species complex), *S. siderea, Stephanocoenia intersepta*	Garzón-Ferreira and Gil, 1998.
Hyperplasia	HP	*D. strigosa, Dichocoenia stokesii*	Peters et al., 1986.
Patchy Necrosis/ White Pox	PX	*Acropora palmata*	Bruckner and Bruckner, 1997; Patterson et al., 2002.
Red Band Disease	RB	*Gorgonia* spp., *C. natans*	Rützler and Santavy, 1983; Richardson, 1993.
White Plague	WP	*D. stokesii, Agaricia agaricites, A. lamarchi, C. natans, Dendrogyra cylindrus, D. labyrinthiformis, D. strigosa, Eusmilia fastigiata, Madracis decactis, M. mirabilis, Manicina areolata, Meandrina meandrites, M. annularis* (species complex), *M. cavernosa, S. siderea, Solenastrea bournoni, Stephanocoenia michilinii,* and *hydrocoral Millepora alcycornis.*	Richardson et al.,1998a, b.
White Band Disease 1	WB1	*A. cervicornis, A. palmata, A. prolifera*	Gladfelter, 1982; Peters, 1993.
White Band Disease 2	WB2	*A. cervicornis*	Ritchie and Smith, 1998.
Yellow Blotch Disease	YB	*M. faveolata, M. annularis*	Santavy et al.,1999b.

Results and Discussion

The percentage of diseased coral colonies ranged from 0-43% among all the sites surveyed during the four sampling periods. No geographic location was consistently identified as a 'hotspot' where a high level of disease was sustained at the same site for multiple survey periods. The greatest percentage of diseased colonies occurred at Looe Key back reef site during summer 1998; 42.9% of all the colonies were diseased, with white pox affecting 41.4% of them. Twelve sites had over 20% of the colonies diseased at a single sampling period, and six occurred during the summer 1998 sampling period (Table 7.14). Five of these six sites occurred in the Key West and Lower Keys regions, with white pox affecting the majority of these colonies. The other site was WH01 in the Dry Tortugas. These disease events co-occurred with the single most severe and massive bleaching event recorded in modern history. Table 7.15 shows the percentage of diseased corals encountered in each region. Each region was not assessed during each survey due to limitations based on level of support available. The 2001 survey was incomplete due to the termination of cruises after the events of September 11, 2001.

Table 7.14. Sites with at least 20% disease prevalence in a survey. Abbreviation for diseases: DS=Dark Spots Disease; PX=White Pox Disease; PX_WB=White Pox Disease and White Band Disease on same colony; SD=Seafan Disease; and WB=White Band Disease. Source: Santavy et al., 2005.

REGION	SITE	YEAR	PERIOD	% DISEASED*	PRIMARY DISEASE	% PRIMARY DISEASE	OTHER IMP. DISEASES
Dry Tortugas	White Shoals 2	1998	Summer	22.86 [9]	SD	17.14	DS, WB
Dry Tortugas	Bird Key 4	1999	Spring	28.33 [6]	PX	27.50	WB
Dry Tortugas	Bird Key 5	1999	Spring	27.37 [8]	PX	27.37	
Key West	Rock Key 3	1998	Summer	27.27 [8]	PX	18.80	WB
Key West	Sand Key 2	1998	Summer	36.61 [3]	PX	16.94	WB, PX_WB
Key West	Sand Key 5	1998	Summer	27.78 [7]	PX	22.22	WB
Lower Keys	E. Sambo 3	1998	Summer	31.91 [5]	PX	31.91	
Lower Keys	Looe Key 3	1998	Summer	42.86 [1]	PX	41.43	WB
Middle Keys	Alligator Reef 2	1998	Spring	22.22 [10]	SD	22.22	
Upper Keys	Carysfort Reef 2	1998	Spring	20.00 [11]	SD	20.00	
Upper Keys	Carysfort Reef 3	1998	Spring	32.29 [4]	SD	23.53	PX
Upper Keys	Carysfort Reef 3	1999	Spring	40.00 [2]	PX	25.00	WB, DS

Table 7.15. Percent diseased colonies for each geographic region sampled from 1998 to 2002. Source: Santavy et al., 2005.

REGION	YEAR	PERIOD	% DISEASED
Dry Tortugas	1998	Spring	4.49
	1998	Summer	4.93
	1999	Spring	4.51
	2000	Summer	4.61
	2002	Summer	3.64
New Grounds	1998	Spring	0.98
	1998	Summer	1.13
	2000	Summer	0.46
Key West	1998	Spring	5.91
	1998	Summer	12.8
	1999	Spring	6.84
	2000	Summer	5.34
	2002	Summer	4.55
Lower Keys	1998	Spring	6.81
	1998	Summer	21.19
	1999	Spring	6.41
	2002	Summer	4.55
Middle Keys	1998	Spring	3.36
	1998	Summer	1.84
	1999	Spring	2.46
	2002	Summer	2.38
Upper Keys	1998	Spring	14.17
	1998	Summer	9.8
	1999	Spring	4.23
	2002	Summer	3.22
Biscayne National Park	1998	Spring	8.77
	1998	Summer	3.91
	1999	Summer	0.6

Acroporid Species in the Upper Keys

Methods

The surviving *Acropora* spp. populations in the Upper Florida Keys are scarce and highly patchy in distribution, requiring a focal monitoring approach. In 1998, annual monitoring of *Acropora palmata* populations and their snail predators (*Coralliophila abbreviata*) was initiated at four sites in the FKNMS. Annual surveys record data on size structure and condition of *A. palmata* colonies at each site as well as snail infestation, damselfish territories, and disease prevalence (see Miller et al., 2002 for complete methods). Since 2002, individual colonies of *Acropora palmata* and *A. cervicornis* have been monitored at four sites in the FKNMS and four sites in Biscayne National Park (BNP). Approximately 20 colonies at each site were chosen to reflect the range of conditions present at that site (e.g., health, disease, predation). Colonies were tagged, mapped, extensively photographed, measured (length, width, and height), assessed for condition, and re-surveyed at 4-5 month intervals.

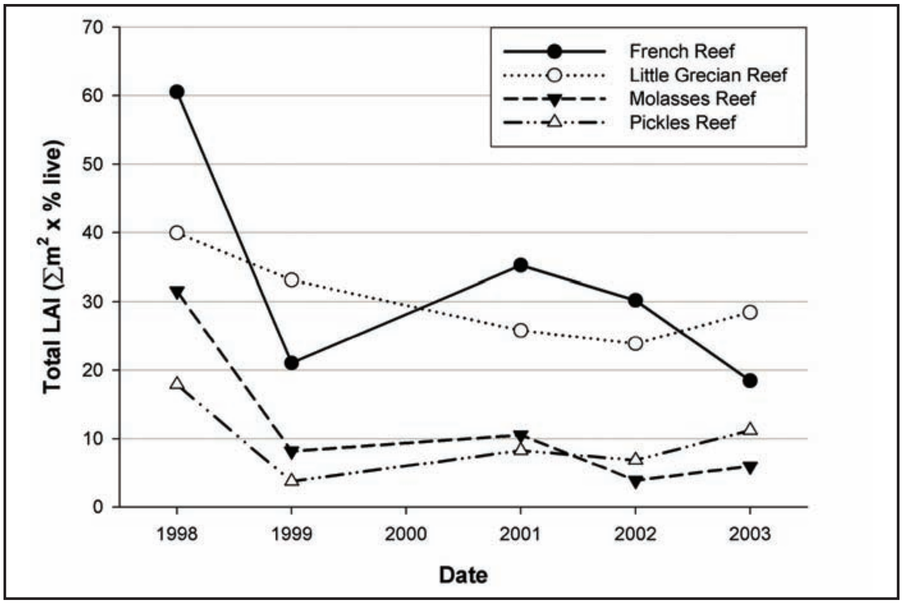

Figure 7.19. Total live area (sum of length x width x % live cover) of *Acropora palmata* at fully censused sites off Key Largo, FL from 1998 to 2003. Source: Miller et al., 2002.

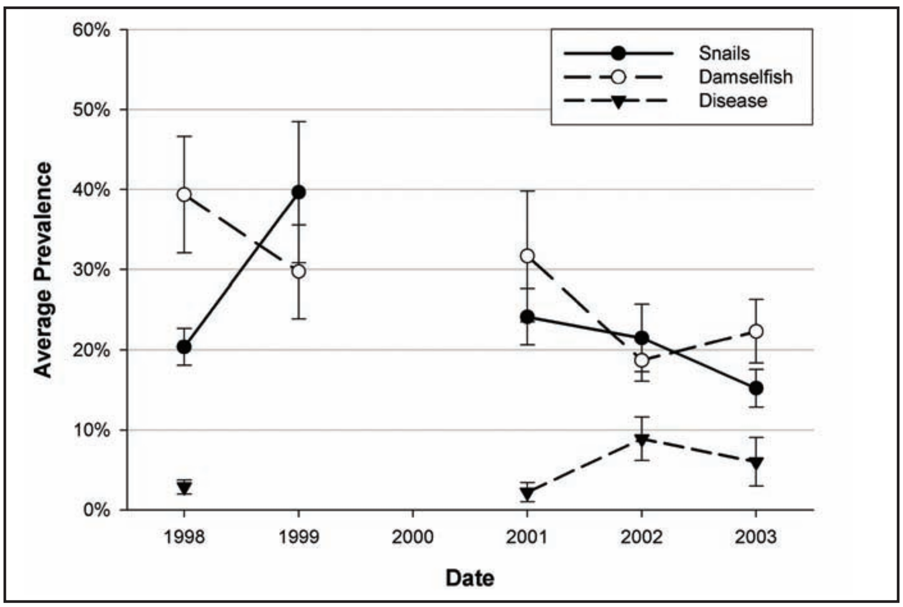

Figure 7.20. Average prevalence of *Acropora palmata* surveyed from reefs (n = 6) in the Upper Florida Keys that were infested with snails (*Coralliophila abbreviata*) inhabited by three-spot damselfish (*Stegastes planifrons*) or displayed active signs of disease (including White Band Disease and White Pox/Patchy Necrosis). Surveys were conducted at 6 reefs including South Carysfort, Horse Shoe, Little Grecian, French, Pickles, and Molasses reefs. Source: Miller et al., 2002.

Results and Discussion

The annual survey of *A. palmata* patches shows that a substantial decline occurred between 1998 and 1999. This interval included two major disturbances: Hurricane Georges and a major bleaching event. Since then, abundance of live coral at these four sites has remained fairly stable but has not shown any recovery (Figure 7.19). The proportion of colonies infested by snail predators increased in 1999 following this decline in coral abundance, but has rebounded back to its previous (1998) level of about 15-20% (Figure 7.20). A similar proportion of colonies are affected by three-spot damselfish biting, but a much smaller percentage of *A. palmata* colonies display signs of active disease (Figure 7.20).

Over most of the study period, predation by snails appeared to be the condition posing greatest impact to recruits of both species in terms of both live tissue loss and decreased growth of individuals. Snail predation is also the most prevalent threat at the population level. However, in April 2003, this individual-based monitoring of *Acropora* spp. colonies led to the discovery of a coral disease outbreak at White Bank Dry Rocks (Figure 7.21). In the observed outbreak, approximately 65% of the *A. cervicornis* colonies had significant or total tissue loss. The tagged population (n=19 colonies) showed a loss of mean colony live tissue coverage from 95% prior to the outbreak to less than 15% in a follow-up survey in February 2004. This event emphasizes the vulnerability of *Acropora* spp. recovery to stochastic events which are difficult, if not impossible to manage or mitigate.

Figure 7.21. An *Acropora cervicornis* colony displays rapid tissue loss at White Bank Dry Rocks, Florida Keys. During this outbreak in spring 2003, many colonies exhibited this condition at several other reef sites in the Florida Keys. Source: Miller et al., 2002.

ASSOCIATED BIOLOGICAL COMMUNITIES

FISH

Fishery-Dependent Monitoring

Various programs that collect data directly from Florida fisheries are summarized in Table 7.16.

Table 7.16. Florida fishery-dependent data collection programs. Source: J. Bohnsack, NOAA Fisheries, SEFSC.

PROGRAM	TARGET	AGENCY	DATE STARTED
Marine Recreational Fishing Statistical Survey (MRFSS)	Recreational fishing from shore, bridge, private, rental and charter boats	NOAA Fisheries	1979
NMFS Headboat Survey	Recreational headboat landings and biostatistical sampling	NOAA Fisheries	1978
Recreational world record gamefish	Largest fish landed by recreational angling by line class and rod type by men and women	International Gamefish Association (IGFA)	1939
Recreational fishing licenses	Recreational marine angling, spiny lobster diving	Florida Fish & Wildlife Conservation Commission	1990
Florida Trip Ticket System	Commercial food fish and invertebrate landings	Florida Fish & Wildlife Conservation Commission	1986
Florida Trip Ticket System	Commercial marine life fisheries	Florida Fish & Wildlife Conservation Commission	1990
General Canvass Landings Statistics (GCLS)	Commercial landings	NOAA Fisheries	1967
Trip Interview Program (TIP)	Commercial biostatistical data	NOAA Fisheries	1985
Commercial Logbook Program	Commercial fishing by fish traps, longlines	NOAA Fisheries	1993
Commercial vessel registrations	Number of commercial vessels	NOAA Fisheries	1985
Biscayne National Park (BNP) Creel Census	Recreational fishing within and adjacent to BNP	Biscayne National Park	1976
Everglades National Park (ENP) Creel Census	Recreational fishing within and adjacent to ENP	Everglades National Park	1972

Florida Fish and Wildlife Conservation Commission

The FFWCC has collected commercial food fish landings since 1986 and commercial marine life fishery statistics since 1990. NOAA Fisheries (U.S. DOC, 2003) collects landings data for commercial and recreational food fisheries, and for recreational charter boats, headboats, private boats and shore fishing. Commercial and recreational spiny lobster fishing effort is reflected by the number of licenses issued (Figures 7.22 and 7.23).

Results and Discussion

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).

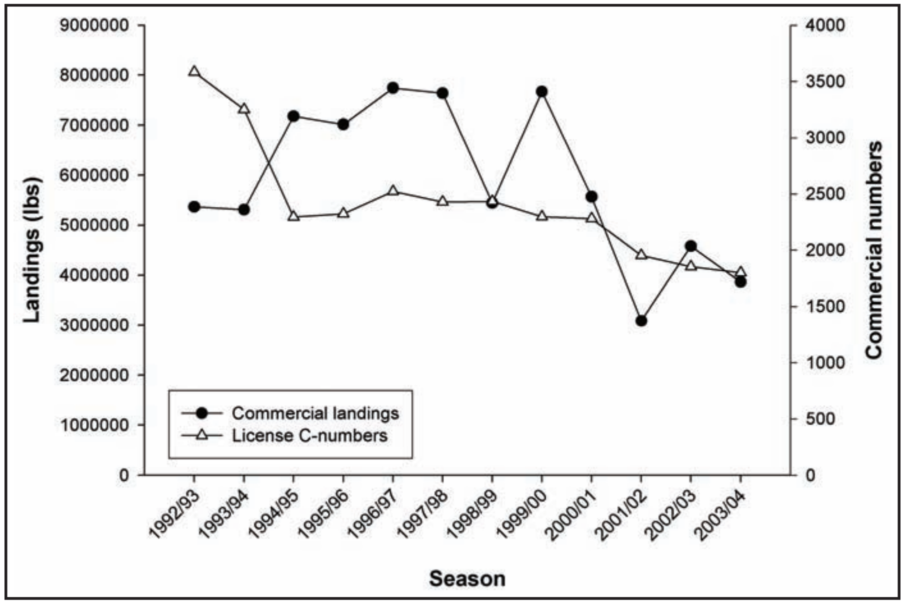

Figure 7.22. Commercial landings and license C-numbers for the spiny lobster fishery in Florida. Commercial landings include catch from traps and from diving. License numbers overestimate the number of vessels since some vessels may have more than one set of C-numbers. Landings for 2003-4 are preliminary. Source: Florida Fish and Wildlife Conservation Commission, unpublished data.

Fishery-dependent reef fish landings trends were reported for the Florida Keys (Bohnsack et al., 1994). Reef fishes accounted for 58% of fish landings. From 1981-1992, mean total annual landings from recreational reef fisheries in the Florida Keys (Monroe County) were 0.107 x 106 kg for headboats in the Tortugas 0.201 x 106 kg for the rest of the Keys, and 1.79 x 106 kg for other recreational fisheries. In comparison, total commercial reef fishery landings were 2.12 x 106 kg for spiny lobster, 1.25 x 106 kg for pink shrimp, 0.17 x 106 kg for grouper, and 1.00 x 106 kg (using 1992 as a benchmark). In the 1980s, pink shrimp landings declined to approximately 40% of previous levels while total grouper declined to less than half of previous levels. Increases in landings were reported for yellowtail snapper, amberjack, and various jacks.

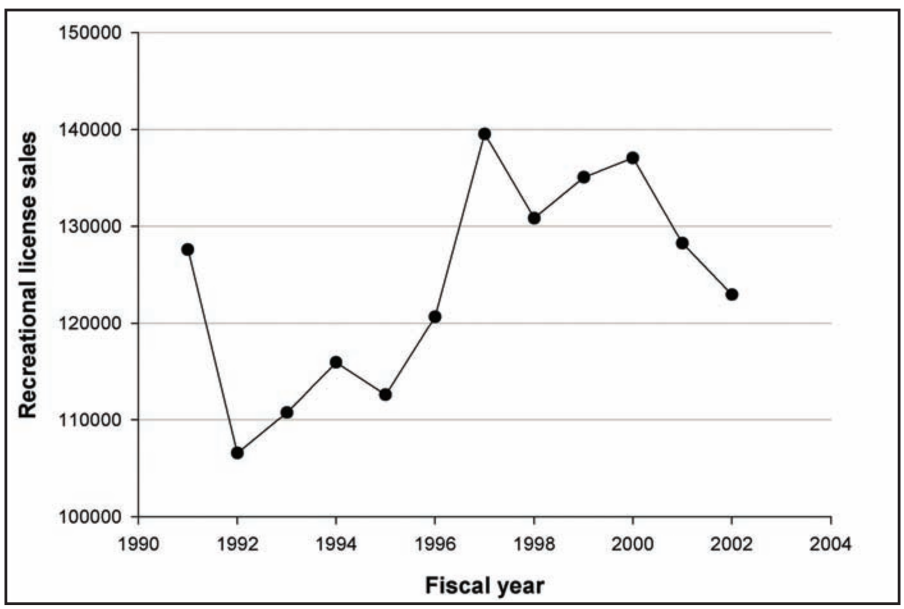

Figure 7.23. Numbers of recreational licenses for the spiny lobster fishery in Florida (1991-2002). Source: Florida Fish and Wildlife Conservation Commission.

Harper et al. (2000) described trends in the recreational hook-and-line and diving fishery in the BNP from 1976-1991 in which more than 170 taxa were recorded. Mean annual landings were 4.77 fish/angler/trip (ranging from 3.80 in 1991 to 5.83 in 1981) and dropped significantly in years following Florida's adoption of new minimum size restrictions in 1985 and 1990. Spiny lobster landings averaged 8.02 per trip and releases averaged 5.73 per trip. Spearfishing accounted for 12% of trips and 10.3% of fish landed by numbers.

In a report to the U.S. Congress (U.S. DOC, 2003) the SAFMC listed six Florida reef fishes (speckled hind, warsaw grouper, black grouper, red porgy, goliath grouper, and Nassau grouper) as either overfished (i.e., depleted below minimum standards) or undergoing overfishing (i.e., being fished at a rate that would lead to overfishing), four species were not overfished and 46 species were in unknown condition. The GMFMC listed two species, goliath and Nassau grouper, as either overfished or undergoing overfishing, while 26 were in unknown condition. More recently hogfish (*Lachnoliamus maximus*) stocks were shown to be overfished and undergoing overfishing in the Florida Keys (Ault et al., 2003) although fishing mortality trends showed a gradual decrease following a fish trap prohibition in 1990 and establishment of minimum size regulations in 1993 (Figure 7.24).

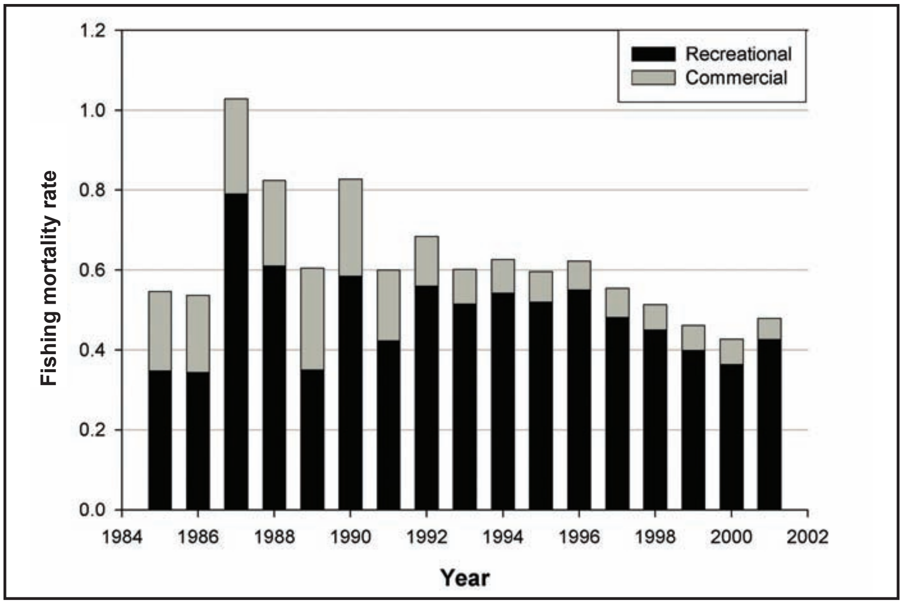

Figure 7.24. Estimated total annual fishing mortality rates (1985-2000) for Florida hogfish showing commercial (light) and recreational (dark) contributions. Source: Ault et al., 2003.

A yellowtail snapper (*Ocyurus chrysurus*) stock assessment (Muller et al., 2003) showed landing trends increased from 1000 mt in 1981 to 1643 mt in 1993, and then declined to 802 mt in 2001. Effort followed a similar trend as landings, increasing to a peak and then declining. Compliance with the 30.5 cm minimum size limit was high. Noncompliance, depending on the region, was 2% for commercial, 4-5% for recreational, and 2-3% for headboat fisheries. Only 0.2% of anglers in the Atlantic region and 1.3% in the Keys exceed the 10 fish per trip limit. The assessment concluded that the stock was neither undergoing overfishing or overfished (http://www.sefsc.noaa.gov/SEDAR2/yellowtailFinal.pdf, Accessed 02/09/05).

Goliath grouper (*Epinephelus itajara*) fishing was closed in Florida and Atlantic waters in 1990 and in the Gulf of Mexico in 1992. In 2003, evidence indicated that the stock was rebuilding and had a 50% chance of being rebuilt by 2006 in its historical core habitat range in southern Florida (Porch et al., 2003).

Fishery-Independent Monitoring

Several monitoring programs collect resource data independent of Florida fisheries.

NOAA Reef fish visual census

Methods

The NOAA Southeast Fisheries Science Center's reef fish visual census (RVC) method has used non-destructive visual survey methods to assess reef fish communities and habitat associations in the Florida Keys since 1979. The goals of the method are to monitor trends and habitat associations of the entire reef fish fauna, and to monitor changes in various MPAs and specifically in FKNMS marine reserves following their establishment in 1997 and 2001. A stationary, centrally located diver in a random 7.5 m-radius plot assesses reef fish composition, abundance (density), and size structure. All species observed for five minutes are listed, counted, and their sizes estimated. Habitat features and depth are also recorded. Details on reef fish monitoring field methods and data processing and analyses are published in Bohnsack and Bannerot (1986) and Bohnsack et al. (1999).

Results and Discussion

The RVC database was used to assess condition and retrospective changes in reef fish stocks in the Florida Keys. Ault et al. (1998) showed that a total of 13 of 16 groupers, seven of 13 snappers, and two of five grunts were found to be below the 30% spawning potential ratio the Federal definition of overfishing at that time. Some stocks appeared to have been chronically overfished since the late 1970s. Thus, 65% of the 35 assessed exploited reef fish stocks were below the then-existing Federal standards for sustainability.

Monitoring of Sanctuary Preservation Areas

Methods

In 1997, the FKNMS established multiple no-take marine reserves, or "sanctuary preservation areas." Annual underwater visual surveys have been conducted to assess changes in reef fish populations in areas open and closed to fishing compared to baselines established between 1994 and 1997.

Results and Discussion

A gradient of fishing impacts in the Florida Keys was found - from a high near human population centers near Miami in the BNP (Ault et al., 2001; Harper et al., 2000) and decreasing to a low southwest to the Dry Tortugas (Ault et al., 2002). In the BNP, the average size fish within the exploited phase for 35 important fishery species has remained relatively constant for the last 25 years and is very close to minimum size of capture and not to the historically unfished population size (Ault et al., 2001). The average size of adult black grouper, for example, was estimated to be 40% of what it was in 1940, fishing mortality was several times the level needed to achieve optimum yield (Figure 7.25), and the spawning stock is now less than 5% of its historical unfished maximum (Figure 7.25).

Overall, 77% of the 35 stocks that could be analyzed were overfished by federal standards, including 13 of 16 grouper species, 11 of 13 snapper, barracuda, and two of five grunt. In addition, stock biomass was below standards for most of the key targeted species within the reef fish fishery (Figure 7.26).

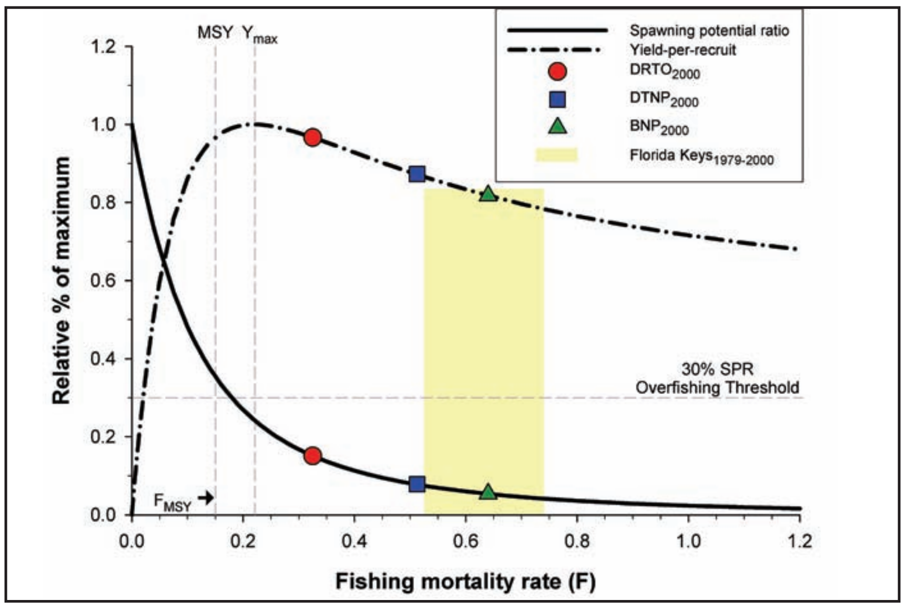

Figure 7.25. Fishery assessment for black grouper, *Mycteroperca bonaci*, in Biscayne National Park and the Florida Keys. Source: Ault et al., 2001.

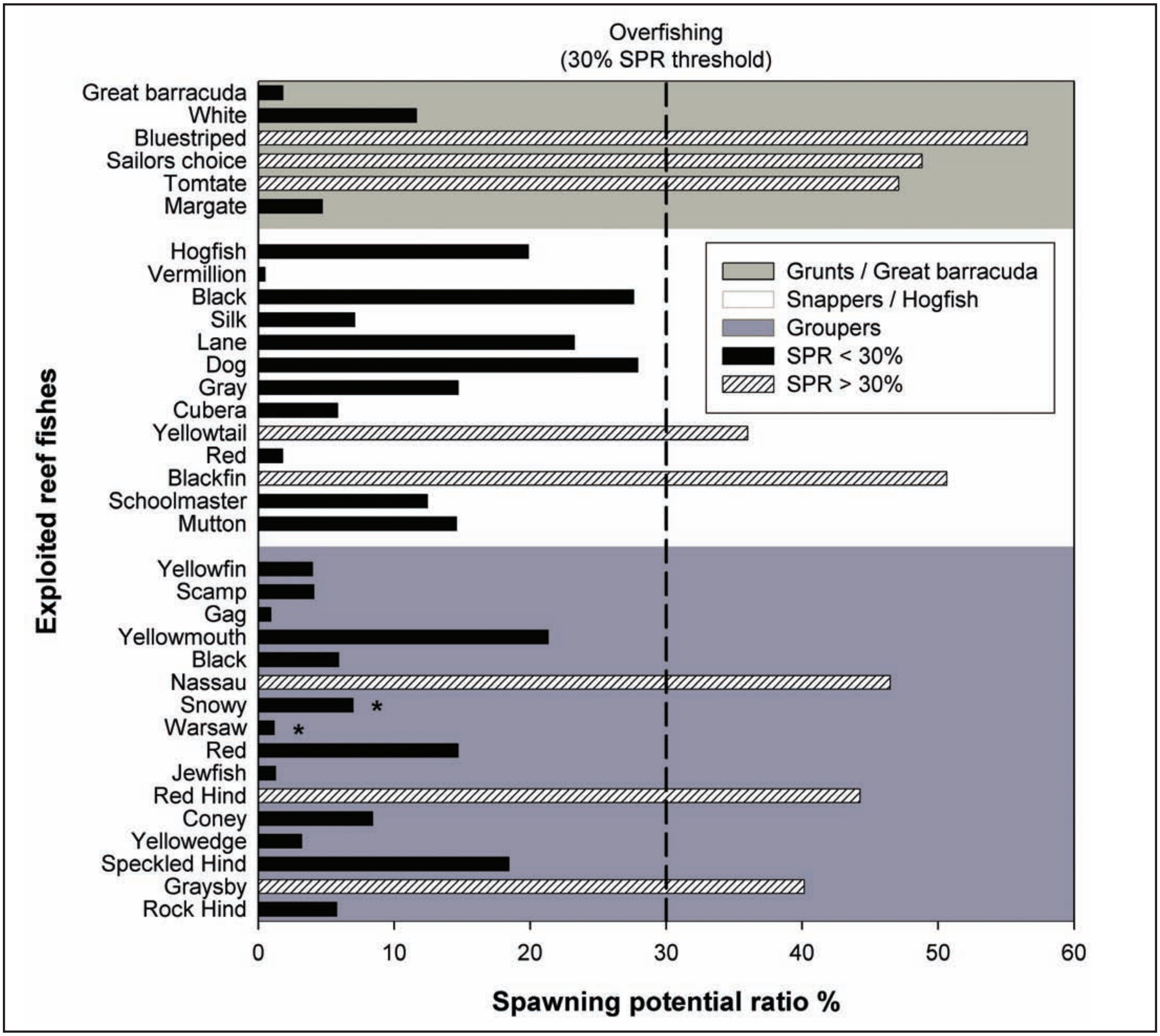

Figure 7.26. Fishery management benchmark spawning potential ratio (SPR) analyses for 35 exploited species of Biscayne National Park-Florida Keys reef fish, comprising groupers, snappers and hogfish, grunts and great barracuda. Filled bars indicate stock ‘overfishing’ and hatched bars indicate the stock is above the 30% SPR (U.S. Federal standard). Asterisk indicates estimate from headboat data outside BNP. The high SPR estimate for Nassau grouper is dubious. Source: Ault et al., 2001.

Changes in no-take and fished zones were assessed and compared to a four-year baseline (1994-1997) established before new zone regulations were implemented in 1997. Although no-take zones established in 1997 comprised only 0.5% of the FKNMS, they included about 5.5% of the reef habitat because no-take zones were preferentially selected to include reefs. Preliminary results showed a significant and dramatic increase in mean density of exploitable-sized individuals, but no significant changes for two species not targeted by fishing. In no-take zones within the first three years (1998-2000), densities of economically important exploitable phase yellowtail snapper (*Ocyurus chrysurus*) (Figure 7.27) and combined grouper (Serranidae) increased significantly compared to baseline levels. In the fourth year, gray snapper (*Lutjanus griseus*) had also increased significantly. In comparison, average densities of two non-exploited species, striped parrotfish (*Scarus croicensis*) and stoplight parrotfish (*Sparisoma viride*), were essentially unchanged compared to baseline performance ranges.

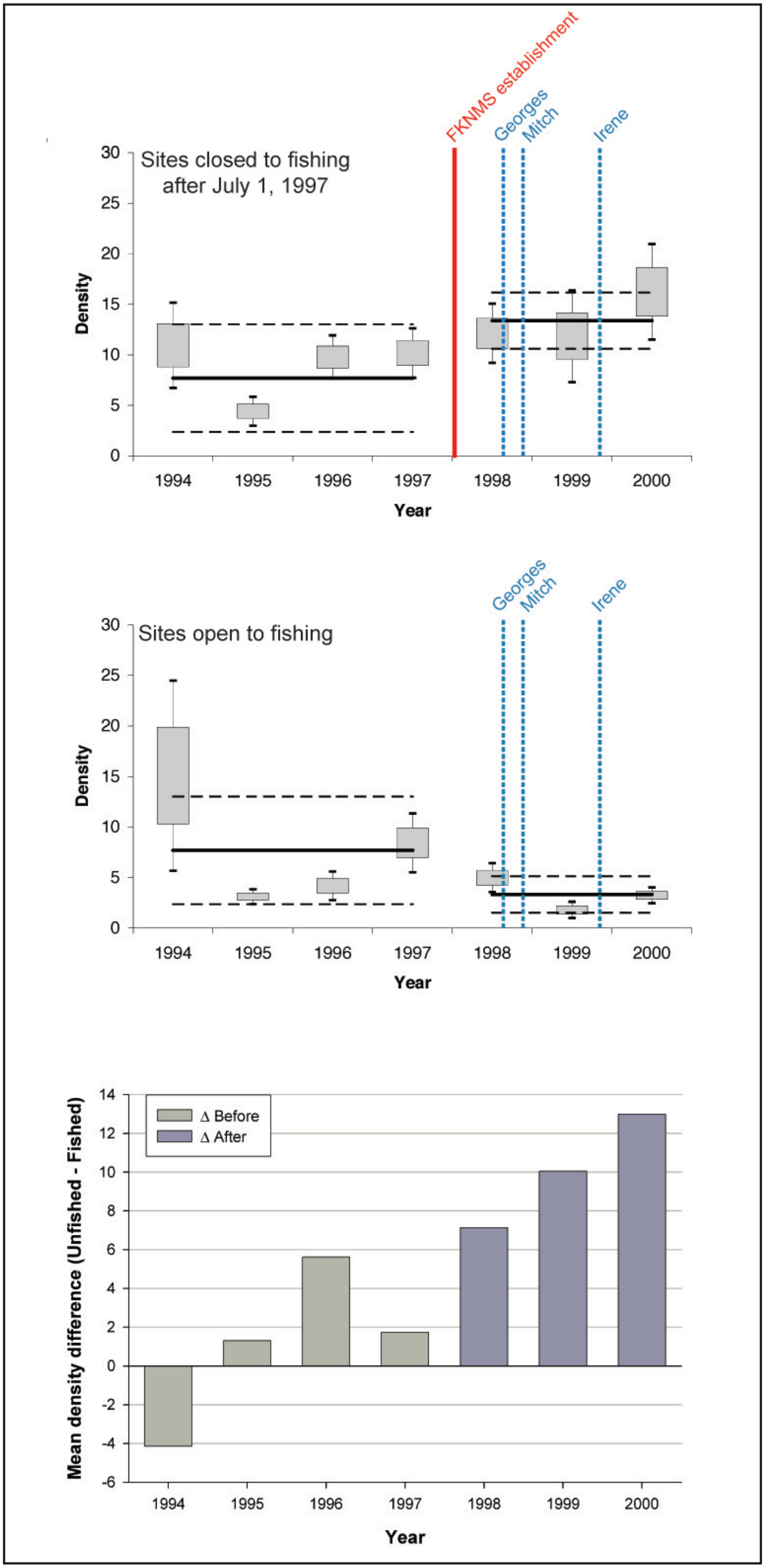

Figure 7.27. Changes in density for yellowtail snapper (*Ocyurus chrysurus*) inside and outside marine reserves in the FKNMS. Source: Ault et al., 2001.

Ferro et al. (2003) used the RVC method to monitor reef fish trends and describe reef composition of the three reef tracts off Broward County, Florida from 1998-2002 (Figure 7.2). They collected 667 samples comprising 86,463 individuals of 208 species from 52 families and showed that reef fish abundance, total biomass and species richness increased from inshore to offshore reefs.

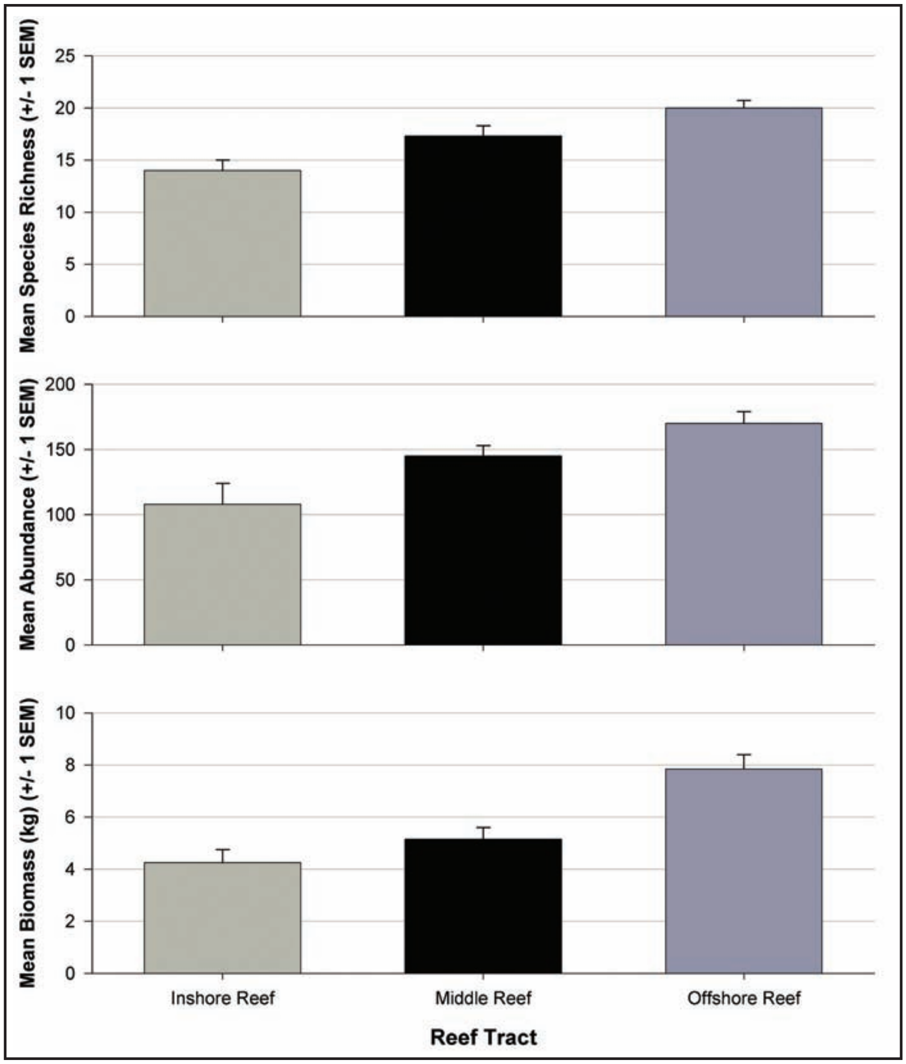

Figure 7.28. Mean fish species richness, abundance, and biomass (n = 667) on the three reef tracts off Broward County, Florida from 1998 to 2002. Source: Ferro et al. 2003.

Reef Environmental Education Foundation Reef Fish Monitoring

The Reef Environmental Education Foundation (REEF) is a nonprofit organization that trains amateur divers to conduct standardized volunteer surveys of reef fishes in an effort to monitor species distributions and changes in reef fish occurrence.

Methods

Volunteers used a roving diver technique (Schmitt and Sullivan, 1996) to develop a comprehensive species list from a dive site and multiple surveys to calculate percent frequency-of-occurrence from a dive site. For each dive, observed species are scored in abundance categories based on what a diver observed. Between 1994 and 2004, over 55,595 individual surveys have been conducted in the Tropical Western Atlantic Ocean. A total of 11,105 surveys were collected in the Florida Keys through 2002. Details of methods are available at http://www.reef.org/ (Accessed 01/23/05).

REEF fish monitoring involves expert REEF divers (members of the Advanced Assessment Team) that visit certain sites to do repeated fish surveys. Figure 7.29 shows trends in sighting frequency for Nassau grouper at no-take reserves and comparable fished sites in the FKNMS. Figure 7.30 shows trends for four angelfish species.

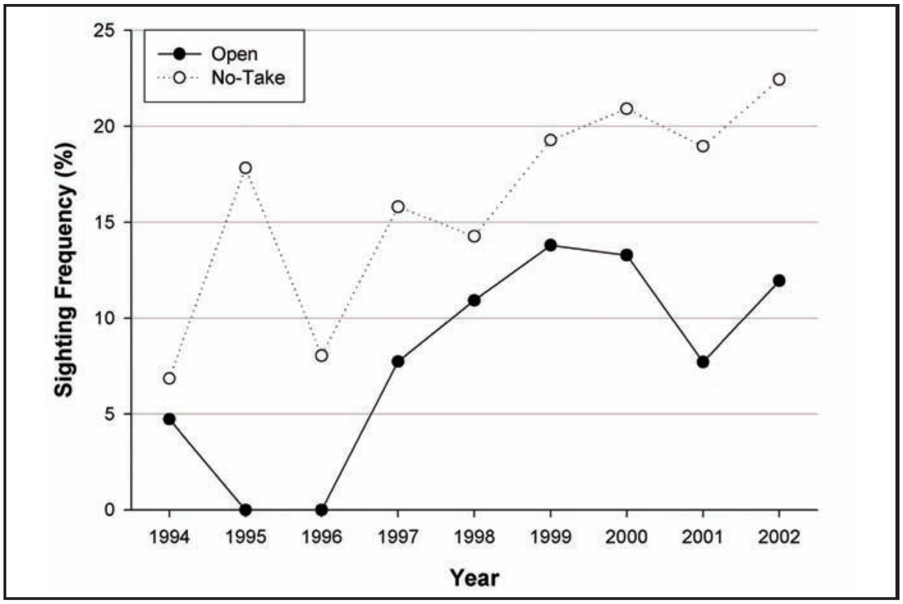

Figure 7.29. Changes in mean sighting frequency for Nassau grouper at 16 reefs in no-take marine reserves and 11 fished reference reefs in the Florida Keys National Marine Sanctuary. Source: Reef Environmental Education Foundation, http://www.reef.org/data/fknms_02.pdf, Accessed 5/3/05.

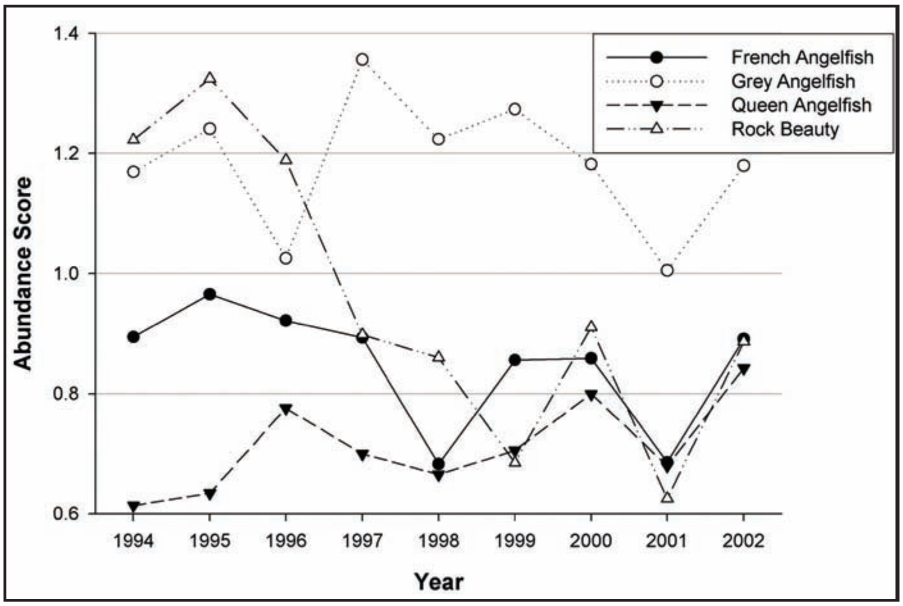

Figure 7.30. Changes in mean abundance scores for four species of angelfish (Pomacanthidae) at 27 sites in the Florida Keys National Marine Sanctuary. Source: Reef Environmental Education Foundation, http://www.reef.org/data/fknms_02.pdf, Accessed 5/3/05.

MACROINVERTEBRATES

FFWCC Spiny Lobster Monitoring

To test the hypothesis that no-take zones would sufficiently protect spiny lobster and that their average abundance and size would increase in protected zones compared to similar fished areas, the FFWCC undertook a lobster monitoring program. Methods included documenting the abundance and size of spiny lobster in 15 no-take and fished reference areas in the FKNMS during the closed and open lobster fishing seasons starting in 1977.

FFWCC Queen Conch Monitoring in the Florida Keys

Methods

The FFWCC initiated a project to monitor the recovery of queen conch (*Strombas gigas*) in the Florida Keys and within no-take marine reserves. Divers conduct belt-transects in locations with conch aggregations, including marine reserves and adjacent reference areas. All conch within 1 m along each 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 7.31). Within aggregations, overall conch density has increased to approximately 700 conch per ha and the area encompassed by the aggregations is approximately 49.5 ha. Approximately 37,000 adult queen conch were observed within breeding aggregations in 2003. Whereas the recovery of conch stock is occurring fairly rapidly in back reef areas, the lack of spawning and poor recovery of conch aggregations in areas immediately adjacent to the islands remain concerns. The FFWCC, University of Florida, and NOAA have started a joint project to examine the effects of xenobiotics on the reproductive development and output of conch from those aggregations.

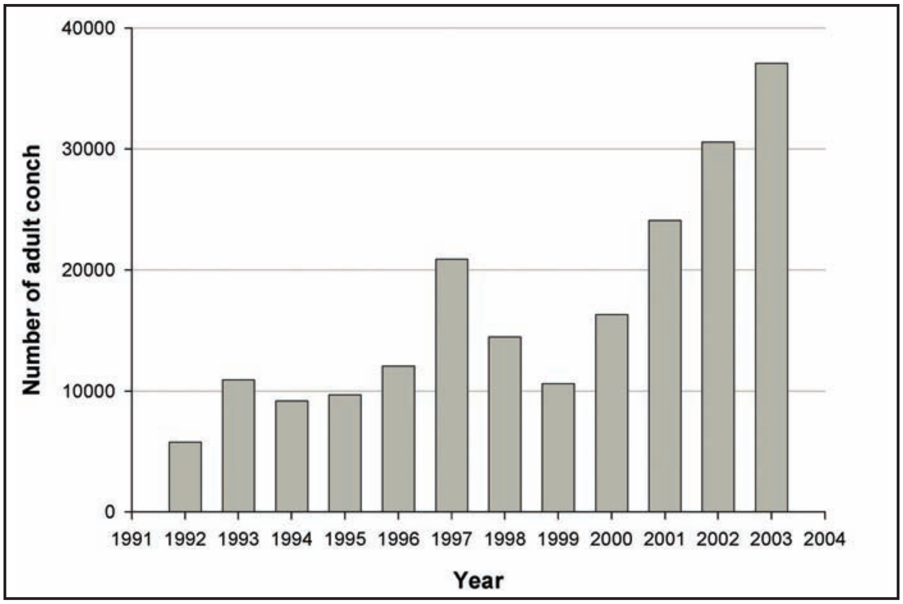

Figure 7.31. Trends in the abundance of adult queen conch, *Strombus gigas*, in the Florida Keys, estimated from yearly monitoring of the breeding aggregations on the backreef. Source: Glazer and Delgado, 2003.

Overall Conclusions and Summary of Analytical Results

Inventories of coral richness show a general decline in stony coral species richness in all reef types and geographic areas. Diseased coral colonies were widely found, although no consistent geographic 'hotspot' was identified. *Acropora* spp. in the Upper Keys declined substantially during 1998-99 due to hurricanes and bleaching; they remain scarce and have exhibited no comeback. Non-native corals and fish have been detected; *Caulerpa brachypus* – a macrophytic algae – is becoming widespread and is of considerable concern.

Effects of coastal pollution on reef communities are not well understood. Elevated nitrogen levels have been detected in nearshore waters, may relate to land use patterns, and have resulted in macroalgal blooms including non-native algal species.

Trends in fisheries effort show a continual increase in the number of recreational anglers in South Florida. A number of key species have exhibited signs of fishing stress. Stocks of the goliath grouper, however, appear to be recovering after a decade of fishery closure.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Mapping

Only about 50% of Florida's coral reef and associated benthic habitats have been mapped. As a result, reliable estimates of the percentage of coral reef and related habitats, as well as the area protected by no-take provisions, cannot be accurately computed statewide.

Mapping efforts were undertaken in the FKNMS in the 1990s. NOAA and FFWCC's Florida Marine Research Institute (FMRI) published digital benthic habitat maps for the Florida Keys in 1998 (FMRI, 1998; Figure 7.32). Recently, the Dry Tortugas region was characterized (Schmidt et al., 1999). Also, Agassiz (1882) produced a remarkable baseline map of Dry Tortugas benthic habitats, which suggests a 0.4 km^2 loss of elkhorn coral in a 100-year period (Davis, 1982). Mapping gaps exist for deeper regions of the Tortugas. The reefs along the Southeastern Florida coast are less well studied. In 1999, Nova Southeastern University's National Coral Reef Institute (NCRI) and the Broward County Department of Planning and Environmental Protection (DPEP) initiated mapping of Broward County reefs. Together with the FMRI, NCRI is presently mapping the reefs of southern Palm Beach and northern Miami-Dade Counties. Maps still need to be completed for the remainder of Miami-Dade and Palm Beach Counties. Reef habitat mapping efforts are underway by the State of Florida and NCRI along the Southeast Florida coast using a variety of techniques including satellite remote sensing, laser-based bathymetry, acoustic bottom classification, and *in situ* diver assessment (Moyer et al., 2003).

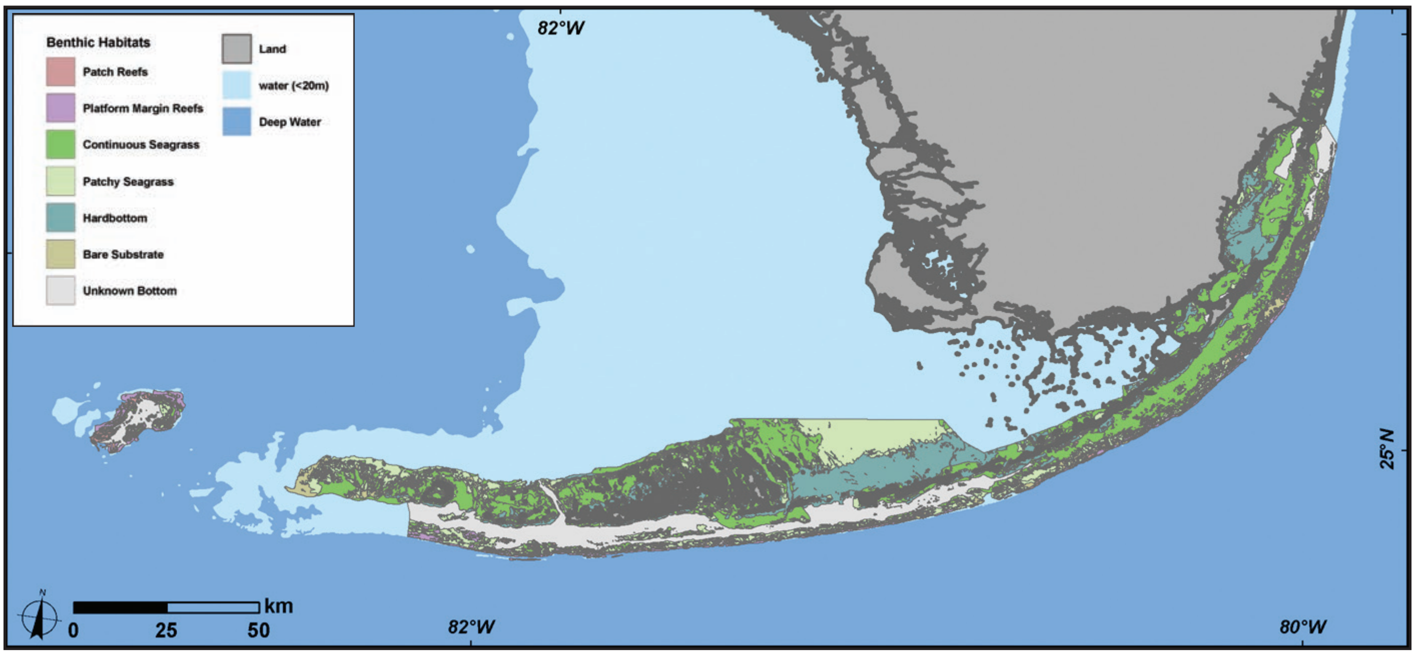

Figure 7.32. Benthic habitat map for the Florida Keys. Map: A. Shapiro. Source: CCMA-BT, http://sposerver.nos.noaa.gov/projects/benthic_habitats/, Accessed 02/14/05.

Improved mapping for specific projects has resulted from aerial photos of nearshore areas and laser-based bathymetry of the three reef tracts off Southeastern Florida. For example, detailed laser depth sounding bathymetry is complete for all of Broward County, offshore to 36 m. A smaller amount of the area is also mapped with multibeam bathymetry and side-scan sonar. Using acoustic seafloor discrimination, NCRI is mapping the distribution of benthic fauna over the reef tracts of Broward County, southern Palm Beach County, and northern Miami-Dade County. The goal is to provide maps that allow quantification of patterns, and thus information on underlying ecological processes. The work proceeds in collaboration with the Broward County DPEP and FMRI.

Estimates of benthic cover are available from some monitoring programs. There is a coral reef distribution map in Jaap and Hallock (1990). No mapping of the Florida Middle Grounds has been conducted to date.

Monitoring, Assessments, and Research

In the FKNMS, a comprehensive research and monitoring program has been implemented to establish baseline information on the various components of the ecosystem and help ascertain possible causes and effects of changes. This way, research and monitoring can ensure the effective implementation of management strategies using the best available scientific information.

Research and monitoring are conducted by many groups, including local, state, and federal agencies, public and private universities, private research foundations, environmental organizations, and independent researchers. Sanctuary staff facilitate and coordinate 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 (WQPP), which began in 1994 and is funded by the EPA and NOAA, is the most comprehensive, long-term monitoring program in the Florida Keys. The program includes monitoring of three components: water quality, seagrasses, and coral/hardbottom communities. Reef fishes, spiny lobster, queen conch, and benthic cover are also monitored throughout the Sanctuary. Water quality has been monitored at 154 fixed stations since 1995. Water samples are collected to measure salinity, temperature, DO, turbidity, relative fluorescence, and light attenuation. The water chemistry study focuses on detecting NO_3^-, NO_2^-, NH_4^+, DIN, and SRP. Concentrations of TON, TOC, TP, and silicate are also measured, along with CHLA and APA (Jones and Boyer, 2001).

Seagrass monitoring through the WQPP allows for the identification of seagrass the distribution and abundance within the Sanctuary and the tracking of changes over time. Quarterly monitoring is conducted at 30 fixed stations and annual monitoring occurs at 206-336 randomly selected sites (Fourqurean et al., 2002). Permanent stations are co-located at 30 of the water quality monitoring sites to help discern relationships between seagrass health and water quality. This long-term monitoring is also invaluable for determining human impacts on the Sanctuary's seagrass communities.

The CREMP tracks the status and trends of coral and hardbottom communities throughout the Sanctuary (Jaap et al., 2001). The project's 43 permanent sites include hardbottom, patch reef, shallow offshore reef, and deep offshore reef communities. Biodiversity, coral condition, and coral cover are recorded annually at four stations within each site, for a total of 172 stations. This project has recently been extended to reefs of Southeast Florida, adding 10 sites throughout Miami-Dade, Broward, and Palm Beach Counties (Gilliam et al., 2004b).

Broward County's Marine Biological Monitoring Program tracks the status and trends of coral and hardbottom communities in the county (Gilliam et al. 2004a). The program's 25 permanent sites located on the nearshore and offshore reef terraces have been monitored yearly since 1997 by the Broward County DPEP and NCRI. Each site consists of one 30-m belt phototransect, two 30-m fish transects, one stationary fish point count, and a sediment trap. Along each belt phototransect, 40 0.75-m^2 quadrat (framer) images are taken; stony coral species (Millepora and Scleractinia) presence, colony size, and condition (diseased or bleached) are recorded; and sponge and octocoral densities are recorded. Fish species abundance and size classes are also recorded along transects and during point counts. Sedimentation rate and grain size analysis is determined bimonthly.

In addition to the WQPP, the FKNMS Zone Monitoring Program monitors the 24 discrete marine reserves located within the Sanctuary. 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, invertebrates, and algae, as well as economic and aesthetic values 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. Lastly, continuous monitoring of certain physical parameters of seawater and ocean conditions are recorded by instruments (C-MAN stations) installed along the Florida Reef Tract as part of the Florida Keys Seascape program (SEAKEYS, 2002). There are six C-MAN stations from Fowey Rocks to the Dry Tortugas and one in Florida Bay. These stations gather data and periodically transmit to satellites, to provide near real-time reports available on the Internet. For the past 10 years, the Sanctuary has maintained a network of 27 thermographs located both inshore and offshore throughout the Keys that record water temperature every two hours.

As baselines are being documented, FKNMS managers are developing a comprehensive science plan outlining specific management objectives and their associated monitoring and research needs. This is an evolving, adaptive management approach to help ensure management decisions are supported by the best available science. The science plan will identify high-priority research and monitoring projects to help fill gaps in understanding the ecosystem and its responses to management actions. Recognizing the importance of an ecosystem approach to management, the Sanctuary engages agencies working on the Comprehensive Everglades Restoration Plan to achieve appropriate restoration goals for the entire ecosystem, including coral reefs and seagrasses. Active monitoring of natural resources is a Sanctuary priority in order to detect changes occurring as a result of water management regimes and restoration.

Along Florida's southeastern coast, much of the present monitoring originated as impact and mitigation studies for activities that had adverse impacts to specific sites (e.g., dredging, ship groundings, pipeline and cable deployments, and beach renourishment). In the past, such studies have been of limited duration (e.g., one to three years) and the focus has been largely on beach renourishment, restoration for grounding impacts, and some baseline data collection from reference areas. Monitoring has begun in Broward County at 25 fixed 30-m^2 sites for environmental conditions (sedimentation quantities and rates, water quality, and temperature), and coral, sponge, and fish abundance and/or cover (Figure 7.33). Assessment studies by NCRI scientists also identify the distribution, abundance, and disease condition of staghorn corals in Broward County. Research on the reproductive status and potential of *Acropora cervicornis* is also being conducted. There have been a number of discrete fish surveys on the reefs of Miami-Dade and Palm Beach Counties, most of which have been associated with beach renourishment projects or artificial reef management (Lindeman and Snyder, 1999; P. Light, pers. comm.; Avila, 2005). However, there is currently a concerted effort underway by NCRI scientists to complete a baseline survey of reef fishes off Broward County (Ettinger et al., 2001; Harttung et al., 2001; Ferro et al., 2003). Initiated in 1998, this NOAA-funded survey is recording fishes on the edges and crests of the three major reef lines.

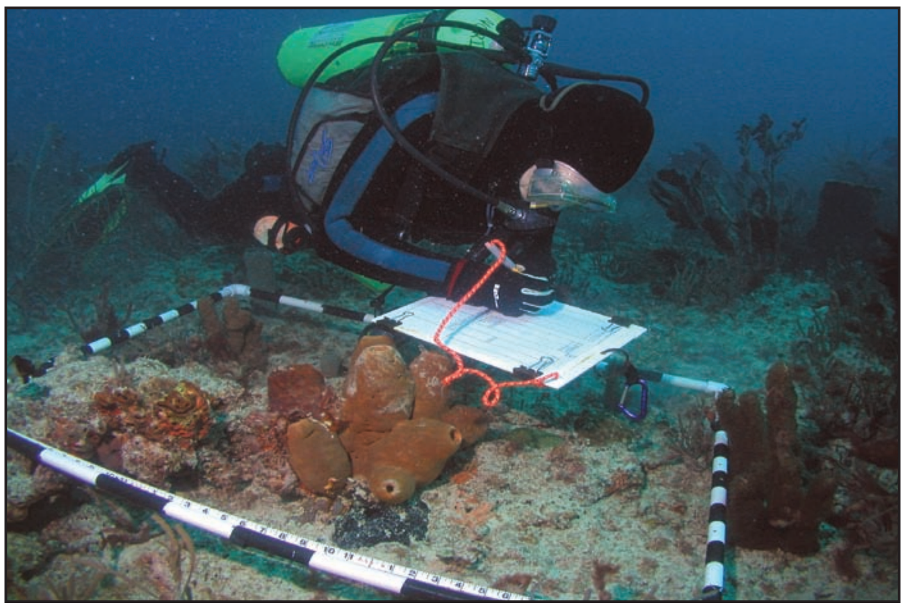

Figure 7.33. Researcher conducting reef monitoring offshore of Broward County, Florida. Photo: D. Gilliam.

The initial survey was completed in 2003 and consists of more than 650 point-counts. In addition, during summer 2001, NCRI scientists inventoried fish on the first 30 m of the inshore reef at 158 m intervals for 25 km of shoreline using multiple visual techniques (point-count, 30 m transects, and 20 minute random swims) (Baron et al., 2001). Broward County now has a database comprised of more than 1,000 visual censuses from the shore to 30 m for reef fish. The NCRI inventory of reefs off Broward County is continuing with a NOAA-funded survey of the fishes in 30-150 m depths using a remotely operated vehicle.

Researchers at NCRI are also currently involved in a multivariate, hypothesis-driven study of the interaction of fish, transplanted corals, coral recruits, and potential coral attractants or optimal substrates (Figure 7.34). Research variables include four potentially different fish assemblages (determined by reef complexity) and biofilm and coral recruitment on settlement plates made of concrete, concrete and iron, concrete and quarry rock, or concrete and coral transplants. Results of this three-year study should yield information critical to reef restoration.

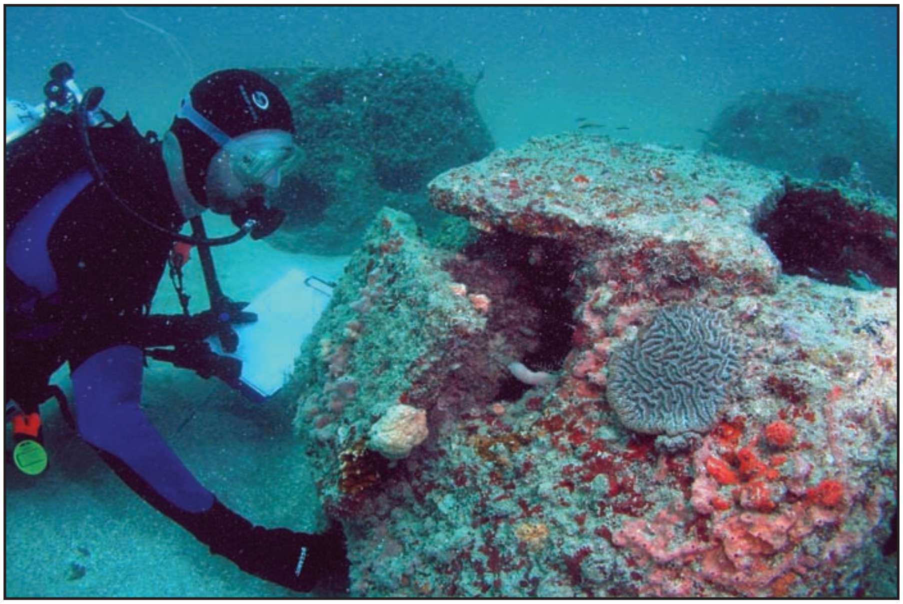

Figure 7.34. Researcher assessing coral recruitment on experimental artificial reef modules offshore of Broward County, Florida. Photo: D. Gilliam.

MPAs and Fully Protected Reserves

As with monitoring, assessment, and research programs, coral reef conservation and management through the designation and implementation of MPAs varies widely. The largest and best-known MPA in Florida, the FKNMS, was designated in 1990, thereby placing 9,850 km^2 of coastal waters and 1,381 km^2 of coral reef area under NOAA and State of Florida management. Immediate protective measures were instituted as a result of Sanctuary designation, including prohibitions on oil and hydrocarbon exploration, mining, and other activities altering the seabed, as well as restrictions on large ship traffic. Coral reefs were protected by prohibiting anchoring on coral, touching coral, and harvesting or collecting coral and 'live rock.' To address water quality concerns, discharges from within the Sanctuary and areas outside the Sanctuary that could potentially enter and affect local resources were also restricted.

In addition, a network of marine zones was instituted in 1997 in the Sanctuary to address a variety of management objectives. Five types of zones were designed and implemented to achieve biodiversity conservation, wildlife protection, and the separation of incompatible uses, among other goals. Three of the zone types (sanctuary preservation areas, ecological reserves, and special use/research-only areas) are fully protected areas, or marine reserves, where lobstering, fishing, spearfishing, shell collecting, and all other consumptive activities are prohibited.

The 1997 zoning plan established 23 discrete fully protected zones that encompass 65% of the Sanctuary's shallow coral reef habitats. The largest zone at that time, the 30.8 km^2 Western Sambo Ecological Reserve, protects offshore reefs as well as other critical habitats, including mangrove fringe, seagrasses, productive hardbottom communities, and patch reefs. In July 2001, the 517.9 km^2 Tortugas Ecological Reserve was implemented (see Figure 7.1). It is now the largest of the Sanctuary's fully protected zones. Located in the westernmost portion of the Florida Reef Tract, the Reserve conserves important deep-water reef resources and fish communities unique to this region of the Florida Keys. Together with the other fully protected zones, the Tortugas Ecological Reserve increased the total protected area of coral reefs within the Sanctuary to 10%.

The Tortugas Ecological Reserve is also significant because it adjoins a 157.8 km^2 research natural area in the Dry Tortugas National Park, a zone where shallow seagrass, coral, sand, and mangrove communities are now conserved. Anchoring is prohibited in the research natural area, and scientific research and educational activities consistent with management of this zone require advance permits from the NPS. To protect important fish nursery and spawning sites, no fishing is allowed in the research natural area. Wildlife viewing, snorkeling, diving, boating and sightseeing are managed in this zone primarily through commercial tour guides. Together, the Sanctuary's Tortugas Ecological Reserve and the Dry Tortugas National Park's research natural area fully protect nearshore to deep reef habitats of the Tortugas region and form the largest, permanent marine reserve in the U.S.

Overall, the Sanctuary management regime uses an ecosystem-wide approach to comprehensively address the variety of impacts, pressures, and threats to Florida Keys marine ecosystems. It is only through this inclusive approach that the complex problems facing coral reefs can be adequately addressed.

The BNP encompasses 683 km^2 of waters just south of Miami, including the majority of Biscayne Bay and a substantial portion of the northern reef tract with 291 km^2 of coral reefs. The Park is renowned for its productive coastal bay, nearshore, and offshore habitats, including islands, mangrove shorelines, seagrass beds, hardbottom communities, and coral reefs, which provide important recreational opportunities and spectacular scenic areas. The NPS is concerned about degradation of BNP resources in the face of coastal development, increases in the number of recreational boats visiting the Park, and fishing pressure. The Park is revising its general management plan to allow for management zones that would give greater protection to Park resources, including natural resources reserve areas where fish nurseries and spawning habitats would be protected from fishing and other disturbances. In addition, the BNP is developing a cooperative plan with the State of Florida to adopt a coordinated and seamless approach to protecting and restoring fishery resources both within and outside Park boundaries.

The Key West National Wildlife Refuge and Great White Heron National Wildlife Refuge overlap with portions of the FKNMS in the backcountry of the lower Keys and an extensive area around the Marquesas Islands between Key West and the Dry Tortugas. The Refuges, established in 1908 and 1938, respectively, contain over 1,619 km^2 of lush seagrass beds, reef tract, patch reefs, hardbottom communities, and pristine mangrove islets. A cooperative agreement between the U.S. Fish and Wildlife Service (USFWS) and State of Florida on the management of these submerged lands created a number of wildlife management zones in the refuges. These zones direct human activities away from sensitive wildlife and habitats, and help ensure their continued conservation. The USFWS, as administrator of the National Wildlife Refuge System, works cooperatively with the State and the FKNMS to protect these sites.

Of the state parks in Southeast Florida, two are considered marine. One of the oldest marine parks in the world (acquisition began in 1959), the John Pennekamp Coral Reef State Park is located in Monroe County on Key Largo. It covers 249 km^2 and has 461 km^2 of coral reefs, seagrass beds, and mangrove swamps. The Lignum Vitae Key Botanical State Park, which includes Shell Key, is located in Monroe County, west of Islamorada. The Park's submerged habitats are located in Florida Bay and the Atlantic Ocean, and include fringing mangrove forest, extensive seagrass beds, patch reef, and sand flats.

Gaps in Monitoring and Conservation Capacity

Current monitoring in the FKNMS has largely focused on detecting changes within the fully protected zones and determining Sanctuary-wide status and trends of water quality, seagrasses, and corals. While some trends are beginning to show and provide a source of hypotheses to be tested continued monitoring is critical. These data will facilitate the detection of long-term changes in communities locally and ecosystem-wide.

Reef monitoring programs in southeastern Florida are limited by a lack of comprehensive inventories of the non-coral components of the marine communities. Baseline assessments of additional sites are needed. Furthermore, new monitoring programs should be developed at sites within counties in the region. The first step should be to develop a functional classification of the reef habitats. For effective selection of monitoring sites, this classification should incorporate criteria to ensure that both representative habitats and unique sites receive attention.

The databases of reef fish in Broward, Miami-Dade, and Palm Beach Counties are based on visual survey techniques that can overlook a substantial number of cryptic species (as many as 37% in a recent Caribbean survey; Collette et al., 2001). Thus, intensive and broad-scale monitoring is necessary to obtain a complete record of resident ichthyofauna. In addition, fish assemblages below a depth of 30 m are poorly characterized, yet they are exploited by recreational fishers. Likewise, the structure and composition of reef fish communities in seagrass and mangrove habitats of Port Everglades and the Intracoastal Waterway remain a mystery to researchers. Such habitats can be important nursery sites for several reef associated fishes (Figure 7.35; Leis, 1991). Given the high level of human activity in these areas, monitoring of reef fish communities is necessary.

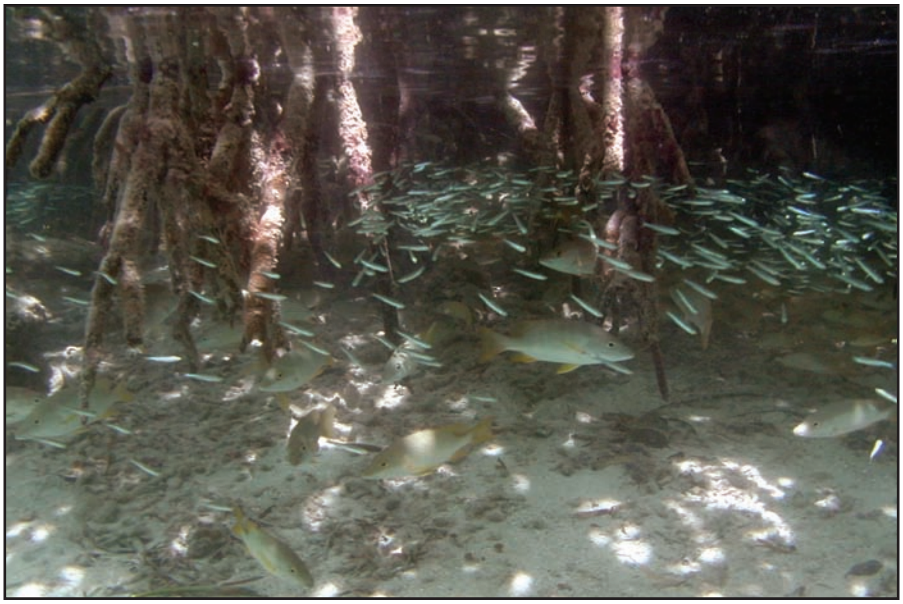

Figure 7.35. Mangrove prop roots serve as an important nursery area for some reef fish species. Photo: M. Kendall.

In May 2002, Coleman and Jaap (W. Jaap, pers. obs.) mounted an expedition to the Florida Middle Grounds to sample sites surveyed by Hopkins in 1975. Data collected at most of the sample stations indicated that the sessile benthic community remained very similar to the status described by Hopkins et al. (1977). However, grouper and snapper populations were extremely depleted. Reefs along the southeast coast and the Middle Grounds banks should be fully mapped to develop map products including a reef atlas similar to that recently published for reef areas off Brazil. The Brazilian reef atlas includes high quality maps, aerial and satellite photographs, underwater habitat photos, and short descriptions of the reefs and resources.

Government Policies, Laws, and Legislation

When President George H. W. Bush signed the Florida Keys National Marine Sanctuary and Protection Act into law in 1990, the FKNMS became the first national marine sanctuary designated by Congress. Authority for the Sanctuary, along with the 12 other national marine sanctuaries, is established under the National Marine Sanctuaries Act of 1972 (16 U.S.C. 1431 et seq., as amended). The FKNMS is administered by NOAA under the U.S. Department of Commerce, and is managed jointly with the State of Florida under a co-trustee agreement because over half of the Sanctuary waters are state territorial waters. The co-trustees agreement commits the Sanctuary to periodically review the Sanctuary's management plan.

In 1997, a comprehensive management plan for the Sanctuary was implemented. It contains 10 action plans and associated strategies for conserving, protecting, and managing the significant natural and cultural resources of the Florida Keys marine environment. Largely non-regulatory, the plan's strategies are to educate citizens and visitors, use volunteers to build stewardship for local marine resources, appropriately mark channels and waterways, install and maintain mooring buoys for vessel use, survey submerged cultural resources, and protect water quality. As previously described the Sanctuary management plan also designated five types of marine zones to reduce pressures in heavily used areas, protect critical habitats and species, and reduce use conflicts. A total of 24 fully protected zones were implemented in 1997 and 2001, covering approximately 6% of the Sanctuary and protecting 65% of shallow bank reef habitats and about 10% of coral reefs.

Most of the smaller zones (sanctuary preservation areas) are located along the offshore reef tracts and encompass the most heavily used spur-and-groove coral formations. In these areas, all consumptive activities are prohibited. The effectiveness of these zones and other biological and chemical parameters are monitored under the FKNMS Research and Monitoring Action Plan.

With guidance from the U.S. Coral Reef Task Force, the Florida Department of Environmental Protection and the FFWCC have coordinated formation of an interagency Southeast Florida Action Strategy Team (SEFAST) for coral reef conservation and management. This team is developing a local action strategy (LAS) to improve coordination of technical and financial support for the conservation and management of coral reefs from the southern Miami-Dade County line to Hobe Sound (Martin County). The Southeast Florida Coral Reef Initiative is targeting this region because the coral habitats are close to shore and co-exist with intensely urbanized areas that lack a coordinated management plan.

SEFAST is made up of four workgroups: Awareness and Appreciation; Fishing, Diving and Other Uses; Land-Based Sources of Pollution and Water Quality; and Maritime Industry and Coastal Construction Impacts. The workgroups are tasked with 1) outlining and presenting issues and threats at stakeholder workshops, 2) combining information from public input and technical advisory committees, 3) further defining threats to coral habitats, and 4) proposing projects to minimize harmful effects. The outcome will be a coordinated plan to address causes of coral degradation and provide a roadmap for successful management.

Commercial fishing remains one of the largest industries in the Florida Keys, but it is regulated heavily by State and Federal fishery management councils. Regulations for most commercial invertebrates and finfish include annual catch quotas, closed seasons, and gear catch size restrictions. The State of Florida also collects landing information on approximately 400 kinds of fish, invertebrates, and plants to track species trends and evaluate regulations. The reefs of southeastern Florida are in state territorial waters and protected from some impacts by state laws and regulations. These include fishing regulations, dredging permits, and a law protecting corals from harvest, sale, or destruction. Broward County has a small boat mooring program intended to reduce anchoring impacts on reefs.

OVERALL STATE CONCLUSIONS AND RECOMMENDATIONS

Due to its high latitude and proximity to the continental U.S., reefs in Florida exist at the environmental extremes for coral. Natural phenomena such as cold fronts and freshwater run-off, as well as heavy use, introduction of non-native species, offshore and coastal construction activities, and water quality degradation are all stressors to Florida's reefs. These factors provide challenges to Florida's coral reef managers and emphasize the need for careful conservation of the resource. Overall, immediate action is needed to curtail alarming declines in coral reef condition throughout Florida.

Habitat maps have been prepared for the Florida Keys and the Tortugas, but only about half of Florida's coral reef and benthic resources have been mapped. Reefs on the southeastern Florida coast are not as well studied as those of the Keys. Broward County has begun a mapping program. NCRI has begun mapping programs in Broward, Palm Beach and Miami-Dade Counties. Mapping has been improved through the use of laser-based bathymetry. Detailed mapping of all benthic resources is essential. The distribution of non-native species - especially *Caulerpa brachypus* - should also be determined, and methods to restrict its spread must be examined.

There are a considerable number of minor and major ship groundings on Florida's reefs resulting in part from increased recreational and commercial boating activity. Groundings result in significant injury to coral, seagrass, and hardbottom resources. The majority of groundings is due to small vessels causing minor damage individually, but considerable cumulative effects. Installation of mooring buoys has reduced the chronic impacts of small boat anchoring. These efforts need to be expanded, especially for large vessels near ports. The State of Florida and the FKNMS have been educating boaters to limit risks and improve navigation in coral reef areas, and these efforts should be expanded.

Large vessel avoidance and Racon beacons in lighthouses have resulted in declines in large vessel groundings. State and FKNMS officials have improved their response to grounding events and improved their restoration methods of damaged sites, thereby reducing the extent of damage. Reef restoration is a fertile field of study necessary to determine effective and efficient ways to restore degraded coral reef ecosystems.

Effects of coastal pollution on reef communities are not well understood, however, there is evidence that it has resulted in macroalgal blooms including non-native species. A comprehensive water quality monitoring program for Southeast Florida does not exist, but is necessary to establish a relationship between water quality and reef community response in the area. Permitting programs have been effective in reducing raw sewage discharges. Monroe County is undertaking a study of the septic tank problem and possible consolidation into regional facilities. Continued monitoring is critical to establish a relationship between coastal activities and coral resource conditions.

Coral reefs provide the ecological foundation for a multibillion dollar fisheries and tourism-based economy in South Florida. Thus reducing fishing pressure is an appropriate goal. The regional fisheries councils and State of Florida have prohibited destructive or wasteful fishing gear, established minimum size and bag limits, as well as seasonal closures, and restricted the taking of some species. Numerous MPAs have been established to restrict fishing. Exploitable species have shown significant increases in these areas. Monitoring and appropriate regulation must be maintained to prevent overfishing.

Management programs in southeastern Florida are limited by a lack of comprehensive inventories. The State of Florida has formed the SEFAST to develop a LAS for coral reef conservation and management in the area. Such a plan is essential if these resources are to co-exist with the intensely urbanized area.

Local communities that are culturally and economically supported by coral reefs are working to employ management strategies and to focus on alleviating controllable human impacts. For example, in southeastern Florida, the environmental impacts of fisheries, dredging, vessel anchorages, vessel groundings, freshwater management, and nutrient inputs should receive attention to maximize reef protection in this area. In the Florida Keys, the community is continuing to pursue solutions that address wastewater and stormwater problems, habitat degradation, and overfishing.

Citizens, stakeholders, elected officials, and resource managers must work together to improve water quality, minimize physical impacts to corals and seagrasses, reduce nonpoint pollution, and increase education to instill a stronger sense of stewardship in Floridians for their coral reefs.

REFERENCES

Agassiz, A. 1882. Explorations of the surface fauna of the Gulf Stream under the auspices of the United States Coast Survey II. The Tortugas and Florida Reefs. Memorandum of the Academy of Arts and Sciences Centennial 2 (1): 107-134.

Atlantic Oceanographic and Meteorological Laboratory (AOML). 1999. Hurricane Georges Leaves Florida Bay Flustered but Not Flushed. 5 pp. Available from the internet URL: http://www.aoml.noaa.gov/flbay/georges/georges_final.html.

Antonius, A. 1985. Coral diseases in the indo-pacific: A first record. Pubblicazioni della Stazione zoologica di Napoli I. Marine ecology 6(3): 197-218.

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. Fishery Bulletin 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. 185 pp.

Ault, J.S., S.G. Smith, G.A. Meester, J. Luo, J., E.C. Franklin, J.A. Bohnsack, D.E. Harper, D.B. McClellan, S.L. Miller, M. Chiappone and D.W. Swanson. 2002. Synoptic habitat and reef fish surveys support establishment of marine reserves in Dry Tortugas, Florida USA. Reef Encounter 31: 22-23.

Ault, J.S., S.G. Smith, G.A. Diaz and E. Franklin. 2003. Florida hogfish fishery stock assessment. Report to the Florida Fish and Wildlife Conservation Commission. 67 pp. plus figures and tables.

Ault, J., J.A. Bohnsack and S.G. Smith. In press. Towards Sustainable Multispecies Fisheries in the Florida USA Coral Reef Ecosystem. Bulletin of Marine Science.

Avila, C. 2005. Offshore reef fish assemblages of Miami-Dade County, Florida: effects associated with dredging for beach renourishments. Master's thesis for Nova Southeastern University.

Banks, K., R.E. Dodge, L.E. Fisher, D. Stout and W.C. Jaap. 1999. Grounding of the nuclear submarine USS MEMPHIS on a southeast Florida coral reef: Impact, assessment, and proposed restoration. pp. 17. In: Proceedings, International Conference on Scienctific Aspects of Coral Reef Assessment, Monitoring, and Restoration.

Baron, R., P. Arena, F. Harttung, D. Fahy, B. Buskirk, L.K.B. Jordan, C. Miller, C. and R.E. Spieler. 2001. In: Proceedings, 54th Annual Meeting Gulf and Caribbean Fisheries Institute.

Bohnsack, J.A. and S.P. Bannerot. 1986. A Stationary Visual Census Technique for Quantitatively Assessing Community Structure of Coral Reef Fishes. NOAA NMFS Technical Report 41.

Bohnsack, J.A., D.E. Harper and D.B. McClellan. 1994. Fisheries trends from Monroe County, Florida. Bulletin of Marine Science 54: 982-1018.

Bohnsack, J.A. and J.S. Ault. 1996. Management strategies to conserve marine biodiversity. Oceanography 9: 73-82.

Bohnsack, J.A., D.B. McClellan, D.E. Harper, G.S. Davenport, G.J. Konoval, A.M. Eklund, J.P. Contillo, S.K. Bolden, P.C. Fischel, G.S. Sandorf, J.C. Javech, M.W. White, M.H. Pickett, M.W. Hulsbeck, J.L. Tobias, J.S. Ault, G.A. Meester, S.G. Smith and J. Luo. 1999. Baseline Data for Evaluating Reef Fish Populations in the Florida Keys. NOAA Techncial Memorandum NMFS-SEFSC-427. 61 pp.

Boyer, J.N. and R.D. Jones. 2002. FY 2002 Annual Report of the Water Quality Monitoring Project for the Water Quality Protection Program in the Florida Keys National Marine Sanctuary. Report for Environmental Protection Agency, South Florida Water Management District and Monroe County by Southeast Environmental Research Center, Florida International University. 47pp.

Boyer, J.N. and R.D. Jones. 2003. FY 2003 Annual Report of the Water Quality Monitoring Project for the Water Quality Protection Program in the Florida Keys National Marine Sanctuary, Executive Summary. Environmental Protection Agency, South Florida Water Management District and Monroe County. 7 pp.

Bruckner A.W. and R.J. Buckner. 1997. Outbreak of coral disease in Puerto Rico. Coral Reefs. 16: 260.

Bruno, J.F., L.E. Petes, C.D. Harvell and A. Hettinger. 2003. Nutrient enrichment can increase the severity of coral diseases. Ecology Letters 6: 105-1061.

Carlton, J.T. 2001. Introduced species in U.S. coastal waters: Environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia. 28 pp.

Carlton, J.T. and J.B. Geller. 1993. Ecological roulette: The global transport of nonindigenous marine organisms. Science 261 (5117): 78-82.

Causey, B.D. 2001. Lessons learned form the intensification of coral bleaching from 1980-2000 in the Florida Keys, USA. pp. 60-66. In: Salm, R.V. and S.L. Coles (eds.) Coral Bleaching and Marine Protected Areas: Proceedings of the Workshop on Mitigating Coral Coastal Marine Program Report #0102.

Chen, E. and J.F. Gerber, 1990. Climate. pp. 11-34. In: R.L. Myers and J.J. Ewel (eds.) Ecosystems of Florida. University of Central Florida Press, Orlando.

Chiappone, M. and R. Sluka. 1996. Fish and Fisheries. Site characterization for the Florida Keys National Marine Sanctuary and environs. Volume 6. Farley Court Publishers, Zenda, Wisconsin.

Continental Shelf Associates (CSA). 2000. Survey 2 report: monitoring reattached hard corals at the *Firat* grounding site. CSA, Jupiter, Florida. 10 pp.

Continental Shelf Associates (CSA). 2001. Hard/live bottom mitigation plan-federal waters. Gulfstream Natural Gas System. CSA, Jupiter, Florida. 15 pp.

Courtenay, Jr., W.R. 1995. Marine fish introductions in southeastern Florida. American Fisheries Society, Introduced Fish Section Newsletter 14 (1): 2-3.

Davis, G.E. 1982. A century of natural change in coral distribution at the Dry Tortugas: a comparison of reef maps from 1881-1976. Bulletin of Marine Science 32 (2): 608-623.

Duane, D.B. and E.P. Meisburger. 1969. Geomorphology and sediments of the nearshore Continental Shelf, Miami to Palm Beach, Florida. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvior, Virginia. Technical Memorandum 29. 47 pp.

Dustan, P. 1977. Vitality of reef coral populations off Key Largo, Florida: Recruitment and mortality. Environmental Geology 2: 51-58.

ENSR International. 2002. 2001 Annual report on live bottom mitigation in Florida state waters for the Gulfstream Natural Gas System, 00449-007-20FM. Tallahassee, FL. 38 pp.

Ettinger, B.D., D.S. Gilliam, L.K.B. Jordan, R.L. Sherman and R.E. Spieler. 2001. The coral reef fishes of Broward County Florida, species and abundance: a work in progress. pp. 748-756. In: Proceedings, 52nd Annual Gulf and Caribbean Fisheries Institute.

Ferro, F., L.K.B. Jordan and R.E. Spieler. 2003. The marine fishes of Broward County, Florida: Final Report of 1998-2002 Survey Results. 73 pp.

Finkl, C.W. and R.H. Charlier. 2003. Sustainability of subtropical coastal zones in southeastern Florida: challenges for urbanized coastal environments threatened by development, pollution, water supply, and storm hazards. Journal of Coastal Research, 19 (4): 934-943.

Finkl, C.W. and S.L. Krupa. 2003. Environmental impacts of coastal-plain activities on sandy beach systems: hazards, perception and mitigation. Journal of Coastal Research SI 35: 132-150.

Florida Marine Research Institute (FMRI). 1998. Benthic habitats of the Florida Keys. Technical Report 4. St. Petersburg. 53 pp.

Fonseca, M.S., B.E. Julius and W.J. Kenworthy, 2000. Integrating biology and economics in seagrass restoration: how much is enough and why? Ecological Engineering 15: 227-237.

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

Garcia, H.E. and L.I. Gordon. 1992. Oxygen solubility in seawater: better fitting equations. Limnology and Oceanography 37: 1307-1312.

Garzón-Ferreira, J. and D. Gill. 1998. Another unknown Caribbean coral phenomenon? Reef Encounters 24: 10.

Gilliam, D.S., S.L. Thornton and R.E. Dodge. 2001. One-Year Post-Baseline Monitoring and Assessment of Coral Reattachment Success and Coral Recruitment, at the C/V *Hind* Grounding Site, Broward County Florida. Florida Fish and Wildlife Commission, Florida Marine Research Institute. 33 pp.

Gilliam, D.S., J.A. Vernacchio and R.E. Dodge. 2003. Nurseries for Reef Fishery Habitat. Final Programmatic Report. National Fish and Wildlife Foundation. 33 pp

Gilliam, D.S., R.E. Dodge, R.E. Spieler, L.K.B. Jordanand J.A. Monty. 2004a. Marine Biological Monitoring in Broward County Florida, Year 4 Annual Report. Broward County Technical Report 04-01. 92 pp.

Gilliam, D.S., B. Ettinger, D. Fahy, E. Fahy, S. Gill, J.A. Monty, L. Shuman and B. Walker. 2004b. Southeast Florida Coral Reef Evaluation and Monitoring Project. Year 1 Report. Florida Fish and Wildlife Commission Florida Marine Research Institute. 12 pp.

Gladfelter, W.B. 1982. White band disease in *Acropora palmata*: implications for the structure and growth of shallow coral reefs. Bulletin of Marine Science 32: 639-643.

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: El Caracol Strombus gigas: Conocimiento Integral para su Manejo Sustentable en el Caribe. D. Aldana Aranda (ed.). CYTED, Programa Iberoamericano de Ciencia y Technología para el Desarrollo, Yucatán, México.

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

Harttung, F.M., P.T. Arena, L.K.B. Jordan, B.D. Ettinger and R.E. Spieler. 2001. Spatial variability of coral reef fish assemblages offshore Broward County, Florida. In: Proceedings, 54th Annual Meeting of the Gulf and Caribbean Fisheries Institute.

Herren, L. 2004. St. Lucie Inlet Preserve State Park Reef Monitoring Progress Report 2. Florida Department of Environmental Protection, Jensen Beach. 43 pp.

Hopkins, T.S., D.R. Blizzard, S.A. Brawley, S.A. Earle, D.E. Grimm, D.K. Gilbert, P.G. Johnson, E.H. Livingston, C.H. Lutz, J.K. Shaw and B.B. Shaw, 1977. A preliminary characterization of the biotic components of composite strip transects on the Florida Middlegrounds, northeastern Gulf of Mexico. pp. 1: 31-37. In: Proceedings, 3rd International Coral Reef Symposium.

Jaap, W.C. 1979. Observation on zooxanthellae expulsion at Middle Sambo Reef, Florida Keys. Bulletin of Marine Science 29 (3): 414-422.

Jaap, W.C. 1984. The Ecology of the South Florida Coral Reefs: A Community Profile. U.S. Fish and Wildlife Service FWS/OBS – 82/08. Washington, D.C. 138 pp.

Jaap, W.C. 2000. Coral reef restoration. Ecological Engineering 15: 345-364.

Jaap, W.C. and P. Hallock, 1990. Coral Reefs. pp. 574-616. In: R.L. Myers and J.J. Ewel (eds.) Ecosystems of Florida. University of Central Florida Press, Orlando.

Jaap, W.C. and M.D. McField. 2001. Video sampling for monitoring coral reef benthos. Bulletin of the Biological Society of Washington 10: 269-273.

Jaap, W.C., J.W. Porter, J.W. Wheaton, C.R. Beaver, K. Hackett, M. Lybolt, M.K. Callahan, J. Kidney, S. Kupfner, C. Torres and K. Sutherland, 2003. EPA/NOAA coral reef evaluation and monitoring project, 2002 executive summary. Florida Fish and Wildlife Conservation Commission and the University of Georgia. St. Petersburg, FL. 28 pp.

Johns, G.M., V.R. Leeworthy, F.W. Bell and M.A. Bonn. 2001. Socioeconomic Study of Reefs in Southeast Florida, Final Report. Broward County Environmental Protection Department, Technical Report 01-10. Available from the internet URL: http://www.broward.org/dni01200.htm.

Jones, R.D. 1996. Phosphorus cycling. pp. 343-348. In: G.J. Hurst, G.A. Knudsen, M.J. McInerney, L.D. Stetzenbach, and M.V. Walter (eds.), Manual of Environmental Microbiology. ASM Press,Materials Park, OH.

Jones, R.D. and J.N. Boyer. 2003. FY2002 Annual Report of the Water Quality Monitoring Project for the Water Quality Protection Program in the Florida Keys National Marine Sanctuary. SERC Technical Report T192. Southeast Environmental Research Center, Florida International University, Miami. Available from the internet URL: http://serc.fiu.edu/wqm-network.

Kim, K. and C.D. Harvell. 2002. Aspergillosis of sea fan corals: disease dynamics in the Florida Keys. The Everglades of Florida Bay, and Coral Reefs of the Florida Keys An Ecosystem Sourcebook 30: 813-824.

Kirk, J.T.O. 1994. Light and Photosynthesis in Aquatic Systems, 2nd edition. Cambridge University Press, Cambridge, UK:

Klein, C.J. and S.P. Orlando, Jr. 1994. A spatial framework for water-quality management in the Florida Keys National Marine Sanctuary. Bulletin of Marine Science 54: 1036-1044.

Kolar, C.S. and D.M. Lodge. 2002. Ecological predictions and risk assessment for alien fishes in North America. Science 298: 1233-1236.

Lapointe, B.E. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and south-east Florida. Limnology and Oceanography. 42 (5): 1119-1131.

Lapointe, B.E. and P.J. Barile. 2001. Discrimination of Nitrogen Sources to Harmful Macroalgal Blooms on Coral Reefs off Southeast Florida. Florida Institute of Oceanography. 27 pp.

Lapointe, B.E. and P.J. Barile. 2003. Invasive macroalgal blooms in coastal southeastern Florida supported by anthropogenic nitrogen. Abstract 81. Estuarine Research Federation, Port Republic, MD.

Larkin, S.L. 2003. The U.S. wholesale marine ornamental market: Trade, landings, and market options. pp. 77-898 In: J.C. Cato and C.L. Brown (eds.) Marine ornamental species. Collection, culture and conservation. Iowa State Press, Ames.

Larkin, S.L. and R.L. Degner. 2001. The U.S. wholesale market for marine ornamentals. Aquarium Sciences and Conservation 3 (1/3): 13-24.

Lee, T.N., M.E. Clarke, E. Williams, A.F. Szmant and T. Berger. 1994. Evolution of the Tortugas gyre and its influence on recruitment in the Florida Keys. Bulletin of Marine Science 54: 621-646.

Lee, T.N., E. Williams, E. Johns, D. Wilson and N.P. Smith. 2002. Transport processes linking South Florida ecosystems. pp. 309-342. In: Porter, J.W. and K.G. Porter (eds.) The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida.

Leeworthy, V.R. and P. Vanasse. 1999. Economic contribution of recreating visitors to the Florida Keys/Key West: Updates for years 1996-1997 and 1997-1998. National Oceanic and Atmospheric Administration, Silver Spring, MD. 20 pp.

Leichter, J.J., H.L. Stewart and S.L. Miller. 2003. Episodic nutrient transport to Florida coral reefs. Limnology and Oceanography 48: 1394-1407.

Leis, J.M. 1991. The pelagic stages of reef fishes: the larval biology of coral reef fishes. pp. 183-230. In P.F. Sale (ed.) The Ecology of Fishes on Coral Reefs. Academic Press, CA. 754 pp.

Light, P. Palm Beach County Department of Environmental Resources Management, West Palm Beach, FL. Personal communication.

Lindeman, K.C. and D.B. Snyder. 1998. Nearshore hardbottom fishes of southeast Florida and effects of habitat burial caused by dredging. Fisheries Bulletin 97: 508-525.

Lirman, D. 2003. A simulation model of the population dynamics of the branching coral *Acropora palmata* Effects of storm intensity and frequency. Ecological Modelling 161: 167-180.

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.). In: Proceedings, Second World Fishery Congress. 797 pp.

Mayer, A.G. 1918. Toxic effects due to high temperature. Carnegie Institution of Washington, Department of Marine Biology 12: 175-178.

McCarty, H.B. and E.C. Peters. 1998. The Coral Disease Page©. Available from the internet URL: http://ourworld.compuserve.com/homepages/mccarty_and_peters/coraldis.htm.

Miami-Dade County Dept. of Environmental Resource Management (DERM). 2003. Third annual report, Bal Harbor mitigation artificial reef monitoring program. DERM, Miami. 20 pp.

Miller, M.W., I.B. Baums, D.E. Williams and A.M. Szmant. 2002. Status of candidate coral, *Acropora palmata*, and its snail predator in the upper Florida Keys National Marine Sanctuary: 1998-2001. NOAA Technical Memorandum NMFS-SEFSC-479. 27 pp.

Milon, J.W. and R.E. Dodge. 2001. Applying habitat equivalency analysis for coral reef damage assessment and restoration. Bulletin of Marine Science 69: 975-988.

Morand, P. and X. Briand. 1996. Excessive growth of macroalgae: a symptom of environmental disturbance. Botanica Marina 39: 491-516.

Moyer, R.P., B. Riegl, K. Banks and R.E. Dodge. 2003. Spatial patterns and ecology of benthic communities on a high-latitude South Florida (Broward County, USA) reef system. Coral Reefs 22 (4): 447-464.

Mueller, E., D.L. Santavy and E.C. Peters. 1998. Survey and quality assurance protocols for the assessment of coral disease distribution. In: Abstracts from European Meeting. International Society for Reef Studies.

Muller, R.G., M.D. Murphy, J. DeSilva and L.R. Barbieri. 2003. Stock assessment report of yellowtail snapper (*Ocyurus chrysurus*) in the Southeast United States. Final Report. FWC-FMRI Report IHR 2003-10. 239 pp.

Myers, R.F. 1991. Micronesian reef fishes, 2nd edition. Coral Graphics, Barrigada, Guam. 298 pp.

Nagelkerken, I., K. Buchan, G.W. Smith, K. Bonair, P. Bush, J. Garzón-Ferreira, L. Botero, P. Gayle, C.D. Harvell, C. Heberer, K. Kim, C. Petrovic, L. Pors and P. Yoshioka. 1997a. Widespread disease in Caribbean sea fans: I. Spreading and general characteristics. pp. 679-682. In: Proceedings of the 8th International Coral Reef Symposium.

Nagelkerken, I., K. Buchan, G.W. Smith, K. Bonair, P. Bush, J. Garzón-Ferreira, L. Botero, P. Gayle, C.D. Harvell, C. Heberer, K. Kim, C. Petrovic, L. Pors and P. Yoshioka. 1997b. Widespread disease in Caribbean sea fans: II. Patterns of infection and tissue loss. Marine Ecology Progress Series 160: 255–263.

National Oceanic and Atmospheric Administration (NOAA). 1997. Scaling Compensatory Restoration Actions. Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990. NOAA Damage Assessment and Restoration Program, Silver Spring, MD.

National Oceanic and Atmospheric Administration (NOAA). 2000. Habitat Equivalency Analysis: An Overview. March 21, 1995 (Revised October 4, 2000). NOAA Damage Assessment and Restoration Program, Washington, DC.

National Research Council. 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. Ocean Studies Board, Water Science and Technology Board. 391 pp.

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

Patterson, K.L., J.W. Porter, K.B. Ritchie, S.W. Polson, E. Mueller, E.C. Peters, D.L. Santavy and G.W. Smith. 2002. The etiology of White Pox, a lethal disease of the Caribbean elkhorn coral, *Acropora palmata*. pp. 99(11): 8725-8730. In: Proceedings of the National Academy of Sciences of the United States of America.

PBS&J. 2000. Six-month monitoring report for repaired corals and artificial reef modules. Jacksonville, FL. 9 pp.

PBS&J. 2003. Arcos-1 North and south cables Sunny Isles, Dade County, Florida. Year two coral restoration and artificial reef monitoring report. Jacksonville, FL. 11 pp.

Peters, E.C., J.J. Oprand and P.P. Yevich. 1983. Possible causal agent of “white band disease” in Caribbean acroporid coral. Journal of Invertebrate Pathology 41: 394-396.

Peters, E.C., J.C. Halas and H.B. McCarty. 1986. Neoplasia in *Acropora palmata*, with a review of reports on anomalies of growth and form in the stony corals. Journal of the National Cancer Institute 76: 895-912.

Porche, C.E., A.M. Eklund and G.P. Scott. 2003. An assessment of rebuilding times for goliath grouper. SEDAR6-RW-3. 25 pp.

REEF (Reef Environmental Education Foundation). 2002. Voluntary reef fish monitoring in the Florida Keys National Marine Sanctuary: 2002 update report. Unpublished report for the Florida Keys National Marine Sanctuary. REEF, Key Largo, Florida. 6 pp.

Richardson, L.L. 1993. Red band disease: a new cyanobacterial infestation of corals. American Academy for Understanding Science 13:153-160.

Richardson, L.L., W.M. Goldberg, R.G. Carlton and J.C. Halas. 1998a. Coral disease outbreak in the Florida Keys: Plague type II. Revista Biologia Tropical 46(5): 187-189.

Richardson, L.L., W.M. Goldberg, K.G. Kuta, R.B. Aronson, G.W. Smith, K.B. Ritchie, J.C. Halas, J.S. Feingold and S.L. Miller. 1998b. Florida's mystery coral-killer identified. Nature 392: 557-558.

Risk, J.J., J.M. Heikoop, E.N. Edinger and M.V. Erdmann. 2001. The assessment 'toolbox': community-based reef evaluation methods coupled with geochemical techniques to identify sources of stress. Bulletin of Marine Science 69 (2): 443-458.

Ritchie, K.B. and G.W. Smith. 1998a, Description of type II white band disease in acroporid corals. Revista Biologia Tropical 46(5): 173-185.

Rohmann, S.O., J.J. Hayes, R.C. Newhall, M.E. Monaco and R.W. Grigg. In press. The Area of Potential Shallow-water Tropical and Subtropical Coral Ecosystems in the United States. Coral Reefs.

Rosenberg, A.A. 2003. Managing to the margins: the overexploitation of fisheries. Frontiers in Ecology and the Environment 1(2): 102-106.

Ruiz-Carus, R., R.E. Matheson, Jr., D.E. Roberts, Jr. and P.E. Whitfield. In press. The western Pacific red lionfish, *Pterois volitans* (Scorpaenidae) in Florida: evidence for reproduction and parasitism in the first exotic marine fish established in state waters. Biological Conservation.

Rützler, K. and D.L. Santavy. 1983. The black band disease of Atlantic reef corals I. Description of the cyanophyte pathogen. Marine Ecology 4: 301-319.

Rützler, K., D.L. Santavy, and A. Antonius. 1983. The black-band disease of Atlantic reef corals III. Distribution, ecology, and development. Marine Ecology 4: 329-358.

Santavy, D.L. and E.C. Peters. 1997. Microbial pests: Coral disease research in the western Atlantic. pp. 1: 607-612. In: H.A. Lessios and I.G. Macintyre (eds.) Proceedings of the 8th International Coral Reef Symposium.

Santavy, D.L., E. Mueller, E.C. Peters, J.W. Porter, V.D. Engle and J.G. Campbell. 1999a. Quality assurance measures associated with coral reef monitoring. pp. 170-171. In: International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration.

Santavy, D.L., E.C. Peters, C. Quirolo, J.W. Porter and C.N. Bianchi. 1999b. Yellow-blotch disease outbreaks on reefs of the San Blas Islands, Panama. Coral Reefs 19: 97.

Santavy, D.L., E. Mueller, E.C. Peters, L. MacLaughlin, J.W. Porter, K.L. Patterson and J. Campbell. 2001 Quantitative assessment of coral diseases in the Florida Keys: Strategy and methodology. Hydrobiologia 460: 39-52.

Santavy, D.L., J.K. Summers, V.D. Engle and L.C. Harwell. 2005. The Condition of Coral Reefs in South Florida. 2000. Using Coral Disease and Bleaching as Indicators. Environmental Monitoring and Assessment 100 (1-3): 129-152.

Schmitt, E.F. and K.M. Sullivan. 1996. Analysis of a volunteer method for collecting fish presence and abundance data in the Florida Keys. Bulletin of Marine Science 59 (2): 404-416.

Schmidt, T.W. and L. Pikula 1997. Scientific studies on Dry Tortugas National Park: an annotated bibliography. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration and U.S. Dept. of the Interior, National Park Service. 108 pp.

Schultz, E.T. 1986. *Pterois volitans* and *Pterois miles*: two valid species. Copeia 1986 (3): 686-690.

Sea Byte, Inc. 2001. Gulfstream Natural Gas Pipeline benthic habitat survey, Florida State Waters. Tequesta, FL. 43 pp.

Semmens, B.X., E.R. Buhle, A.K. Salomon and C.V. Pattengill-Semmens. 2004. A hotspot of non-native marine fishes: evidence for the aquarium trade as an invasion pathway. Marine Ecology Progress Series 266: 239-244.

Shinn, E.A. 1963. Spur and groove formation on the Florida reef tract. Journal of Sedimentary Petrology 33 (2): 291-303.

Simberloff, D., D.C. Schmitz and T.C. Brown (eds.). 1997. Strangers in paradise: Impact and management of nonindigenous species in Florida. Island Press, Washington, DC. 479 pp.

Smith, G.W., L.D. Ives, I.A. Nagelkerken and K.B. Ritchie. 1996. Caribbean sea-fan mortalities. Nature 383: 487.

Sprung, J. Two Little Fishes, Inc. Coconut Grove, FL. Available from the internet URL: http://www.twolittlefishies.com.

Summers, J.K., J.F. Paul and A. Robertson, 1995. Monitoring the ecological condition of estuaries in the United States. Environmental Toxicology and Chemistry 49: 93-108.

Taylor, J.N., W.R. Courtenay and J.A. McCann. 1984. Known impacts of exotic fish in the continental United States. pp. 322-373 In: W.R. Courtenay, Jr. and J.R. Stauffer (eds.) Distribution, biology and management of exotic fishes. John Hopkins University Press. Baltimore, Maryland.

Thornton, S.L., D.S. Gilliam, R.E. Dodge, R.E. Fergen and P. Cooke. 2002. Success and growth of corals transplanted to cement armor mat tiles in Southeast Florida: Implications for reef restoration. pp. 1: 955-962. In: Proceedings, 9th International Coral Reef Symposium.

Tomascik, T. 1991. Settlement patterns of Caribbean scleractinian corals on artificial substrata along a eutrophication gradient, Barbados, West Indies. Marine Ecology Progress Series 77: 261-269.

U.S. Census Bureau (USCB). 2003. Census of Population and Housing, Summary Social, Economic, and Housing Characteristics, PHC-2-11, Florida. USCB, Washington, DC. Available from the internet URL: http://www.census.gov/prod/cen2000/phc-2-11.pdf.

U.S. DOC (Department of Commerce). 1996. Strategy for Stewardship: Florida Keys National Marine Sanctuary Final Management Plan/Environmental Impact Statement. National Oceanic and Atmospheric Administration, Silver Spring, MD. Available from the internet URL: http://floridakeys.noaa.gov/regs.

U.S. DOC (Department of Commerce). 2003. Fisheries of the United States, 2002. Current Fishery Statistics No. 2002. U.S. DOC, Washington, DC. 126 pp. Available from the internet URL: http://www.st.nmfs.gov/st1/fus/current/2002-fus.pdf.

U.S.G.S. (U.S. Geological Survey) 1998. Hurricane effects on wildlife and ecosystems. 5 pp. U.S.G.S., Washington, DC. Available from the internet URL: http://biology.usgs.gov/pr/newsrelease/1998/12-8.html.

U.S.G.S. (U.S. Geological Survey) Nonindigenous Aquatic Species. 2003. U.S.G.S., Washington, D.C. Available from the internet URL: http://nas.er.usgs.gov/queries/default.asp.

Vargas-Ángel, B. and J.D. Thomas. 2002. Sexual reproduction of *Acropora cervicornis* in nearshore waters off Broward County, Florida, USA. Coral Reefs 21: 25-26.

Vargas-Ángel, B., J.D. Thomas and S.M. Hoke. 2003. High-latitude *Acropora cervicornis* thickets off Fort Lauderdale, Florida. Coral Reefs 22: 465-472

Vargas-Ángel, B., S.B. Colley, S.H. Hoke and J.D. Thomas. In preparation. The reproductive seasonality and gametogenic cycle of Acropora cervicornis off Broward County, Florida.

Vaughan, T.W. 1911. Recent Madreporaria of southern Florida. Carnegie Institution of Washington Year Book 8: 135-144.

Vaughan, T.W. 1914. Building of the Marquesas and Tortugas Atolls and a sketch of the geologic history of the Florida reef tract. Carnegie Institution, Washington, D.C. Publication 182. Papers from the Department of Marine Biology 5: 55-67.

Visit Florida Year-in-Brief. 2003. Available from the internet URL: http://www.visitflorida.org/_pdf/partner_research/YearInBrief/2003YearInBrief.pdf.

Weil, E. and N. Knowlton. 1994. A multi-character analysis of the Caribbean coral *Montastraea annularis* (Ellis and Solander, 1786) and its two sibling species, *M. faveolata* (Ellis and Solander,1786) and *M. franksi* (Gregory,1895). Bulletin of Marine Science 55: 151-175.

Whitfield, P. E., T. Gardner, S.P. Vives, M.R. Gilligan, W.R. Courtenay, Jr., G.C. Ray and J.A. Hare. 2002. Biological invasion of the Indo-Pacific lionfish *Pterois volitans* along the Atlantic coast of North America. Marine Ecological Progress Series 235: 289-297.

Wittenberg, M. and W. Hunte. 1992. Effects of eutrophication and sedimentation on juvenile corals, I. Abundance, mortality and community structure. Marine Biology 112: 131-138.