STATUS OF CORAL REEFS IN FLORIDA

Billy D. Causey, Richard E. Dodge, Walter Jaap, Ken Banks, Joanne Delaney, Brian D. Keller, and Richard Spieler

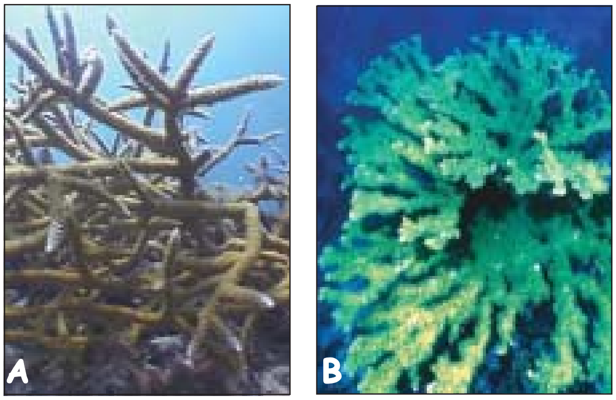
Introduction

There are three main areas of coral reefs and banks in Florida – the Florida Keys, the southeastern coast from northern Monroe County to Palm Beach County, and the Florida Middle Grounds in the eastern Gulf of Mexico, south of Apalachicola and northwest of Tarpon Springs. Numerous coral habitats are also scattered from the Florida Middle Grounds to the Florida Keys along Florida's west coast shelf at varying locations. New communities are constantly being discovered, such as those recently documented along Pulley's Ridge in 45-60 m (150-200 ft) of water.

The Florida Keys – The Florida Keys have the only emergent coral reefs off the continental United States. Arching southwest 356 km from south of Miami to the Dry Tortugas, the Florida reef tract comprises one of the largest reef communities in the world. Except between Rebecca Shoal and the Dry Tortugas, it is almost continuous.

The majority of the reef tract lies within the boundaries of the 9800 km^2 Florida Keys National Marine Sanctuary (FKNMS or Sanctuary). Over half of the Sanctuary is located in State of Florida territorial waters (less than 4.8 km from shore in the Atlantic waters and less than 16.5 km from shore in the Gulf of Mexico); the rest of the Sanctuary (42%) is in Federal waters. Designated in 1990, the Sanctuary is managed jointly between NOAA and the State. A comprehensive management plan adopted in 1997 guides Sanctuary management. One management component has been establishing and implementing five types of marine zones, which include 24 individual, fully protected zones designed to offer added protection to some of the over 1,400 km^2 of coral reef habitat located within the Sanctuary.

Figure 143. A. Staghorn coral (Photo: NCRI); B. elkhorn coral (Photo: Paige Gill, FKNMS).



Two additional marine protected areas managed by the National Park Service encompass reefs in the Florida Keys. Located on the northern boundary of the Sanctuary just south of Miami, Biscayne National Park has 683 km^2 of coastal waters. At the western-most end of the reef tract lies Dry Tortugas National Park, covering 262 km^2.

The Florida Reef Tract has been described as a bank reef system comprised of an almost continuous reef community with elongated reef habitats paralleling one another. The reef ecosystems consist of distinct habitat types: nearshore patch reefs, mid-channel reefs, offshore patch reefs, seagrass beds, back reefs/reef flats, bank or transitional reefs, intermediate reefs, deep reefs, outlier reefs, and sand/soft bottom areas. In addition to the bank reefs, over 6000 circular to oval patch reefs lie along the Florida Reef Tract in 2 to 9 m of water. An outer reef tract lies 4.8 to 11.3 km east and south of the Keys.

The seaward-facing spur and groove formations of the Florida Reef Tract are constructional features, formed partly by wave energy (Shinn 1963, Shinn *et al.* 1981, DoC 1996). They extend 1 to 2 km off the main reef, from 1 to 10 m. Historically, the tops of the spurs were composed mainly of elkhorn coral (*Acropora palmata*, Fig. 143), especially at depths less than 5 m, while grooves contained carbonate sands and reef rubble (Hendler *et al.* 1995). These features are typically no more than 200 m long from offshore to onshore.

Primary corals found in this area include the star corals (*Montastrea annularis* complex and *the* great star coral (*Montastrea cavernosa*), masssive starlet coral (*Siderastrea siderea*), and fire corals

(*Millepora* spp.). Mustard hill coral (*Porites astreoides*), finger coral (*Porites porites*), and lettuce coral (*Agaricia agaricites*) are also common species. Staghorn and elkhorn corals, formerly common or dominant species at 3-15 m, are much less abundant at this time.

The Southeastern Coast – This reef system runs from northern Monroe County to Palm Beach County in a series of discontinuous reef lines paralleling the shore. Duane and Meisburger (1969) and Goldberg (1973) defined the habitat at limited locations and provided information on the coral fauna.

There are generally three lines of reef – one that nominally crests in 3 to 4 m of water (First Reef), another in 6 to 8 m (Second Reef), and a third in 15 to 21 m (Third Reef).

The First Reef has a very low profile with conspicuous small octocoral and algal cover. The substrate is relict reef of Anastasia Formation limestone and worm reef (*Phragmatopoma*), with breaks and sediment pockets within the reef. Typical sessile organisms are lesser starlet coral (*Siderastrea radians*) and colonial zoanthids (*Palythoa mammalosa* and *P. caribaeorum*).

Figure 144. Octocorals with their polyps extended at night (Photo: FKNMS and Joe Seger).

The Second Reef is also flat with somewhat more relief and dissecting channels. Octocorals are most conspicuous, some areas exceeding 60 per m^2 (Fig. 144). Abundant stony corals include knobby brain coral (*Diploria clivosa),* elliptical star coral (*Dichocoenia stokesii*), great star coral, and smooth star coral (*Solenastrea bournoni*). In the past few years, there has been vigorous recruitment of staghorn coral and some extensive aggregations are now present off Broward County. Here, reef-like accumulations or "thickets" of this species form a significant habitat. Spawning was documented in early August 2001 (Vargas-Ángel and Thomas in press).

The Third Reef often has strong 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 Second Reef. Moderate-sized colonies of star corals are common.

The Middle Grounds – This is a 1,193 km^2 area in the eastern Gulf of Mexico (Florida Fish and Wildlife Conservation Commission 2001), 137 km south of Apalachicola and 129 km northwest of Tarpon Springs. Its banks are two parallel ridgelines separated by a valley lying in a north-northwesterly direction. Individual banks are 12 to 15 m high with shallow crests 21 m below sea level. The reef structures are late Pleistocene to early Holocene (Brooks and Doyle 1991).

Winter temperatures reach 16˚ C, limiting many tropical species from occupying these banks. However, there are 23 species of stony corals (Grimm and Hopkins 1977). Environmental studies in the 1970s documented 103 species of algae, about 40 sponges, 75 mollusks, 56 decapod crustaceans, 41 polychaetes, 23 echinoderms, and 170 species of fish (Hopkins *et al.* 1977). Elliptical star coral, yellow pencil coral (*Madracis decactis*), and branching fire coral (*Millepora alcicornis*) are the most abundant stony coral species. Coral cover may be as high as 30% on some pinnacles.

Overall, the biotic characteristics of this area are very different from either the Florida Keys or the Flower Garden Banks, located off Texas.

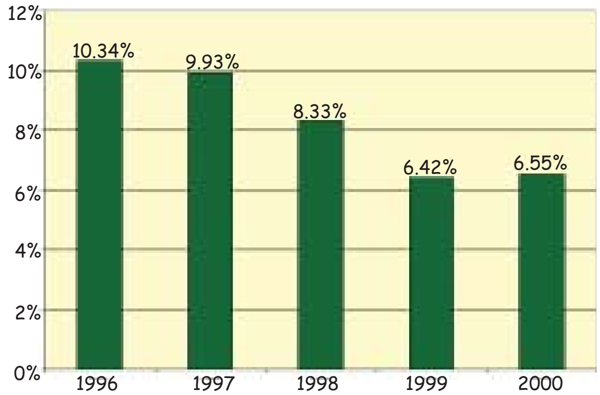


Figure 145. Mean percent stony coral cover at 160 stations in Florida Keys National Marine Sanctuary, 1996-2000 (Modified from Jaap et al. 2001).

Condition of Coral Reef Ecosystems

Historical fluctuations in sea level have influenced the reefs of Florida, with the last significant rise in sea level starting about 6,000 years ago. Since that time, the reefs off Southeast Florida and the Florida Keys have been building. Greater reef development in those areas generally occurs in the Upper and Lower Keys, where the Keys protect reefs from direct water flows from the Gulf of Mexico and Florida Bay (DoC 1996, Robbin 1981, Shinn *et al.* 1989).

Although the reefs of Florida have existed for the past several thousands years, they have only recently become the focus of scientific research and monitoring in an attempt to fully understand changes over time. Since the creation of the FKNMS, the reefs and associated marine habitats of the Florida Keys have become the subject of a broad research and monitoring program that seeks to establish baseline data on ecosystem condition and ascertain cause-and-effect linkages. The reefs and banks of Florida's southeastern coast and the Middle Grounds are not as well studied as those of the Florida Keys, though they are beginning to be mapped and estimates of cover are available from some monitoring programs. As a result, the condition of Florida's coral ecosystems can be best determined for Florida Keys reefs at this time; comprehensive, long-term monitoring of various ecosystem components is critical for the southeastern coast and Middle Grounds.

In the Florida Keys, Sanctuary-wide monitoring of water quality, seagrasses, and coral and hardbottom communities began in 1994 under a Water Quality Protection Program that was jointly undertaken by NOAA and the U.S. Environmental Protection Agency (USEPA). In 1997, when a network of fully protected zones, or marine reserves were implemented, a Zone Monitoring Program was initiated to determine whether the zones meet their objectives of reducing pressure on heavily used reefs, preserving biodiversity, facilitating research, and reducing use conflicts, among others. Each of these monitoring programs and their methods are described in the Current Conservation Management section of this report. To date, over five years of data from the Water Quality Protection Program and three years of data from the Zone Monitoring Program have provided Sanctuary managers with emerging trends in coral reef ecosystem health throughout the Florida Keys.

Coral – Early surveys of Florida Keys coral reefs have documented two species of fire coral, 55 species of octocoral, and 64 taxa of stony corals (DoC 1996, Levy *et al.* 1996).

Under the Zone Monitoring Program, scientists from the University of North Carolina at Wilmington's National Undersea Research Center (UNCW/NURC) have more recently conducted rapid, large-scale assessments of coral reefs and hardbottom communities in the Sanctuary. In their 1999 assessment, the UNCW/NURC rapid assessment and rmonitoring program found coral cover highly variable by both habitat type and region (Miller *et al.* 2001). Jaap *et al.* (2001) confirmed that gains and losses of coral cover in the Florida Keys fluctuate among habitat types with patch reef habitats suffering the fewest losses and exhibiting the highest average percent cover over time.

Since 1996, over 66% of 160 stations in the Coral Reef/Hardbottom Monitoring Project of the Water Quality Protection Program exhibited losses in stony coral diversity. From 1996 to 2000, stony coral cover Sanctuary-wide decreased by 36.6% to a low of 6.6% in 2000, with the greatest relative change occurring in the Upper Keys (Jaap *et al.* 2001, Fig. 145). During this time, 67% of monitoring stations had reduced stony coral species richness, 20% gained species, and 13% had unchanged species richness (Jaap *et al.* 2001). However, positive trends were noted in the 1999-2000 survey period, when 69 stations had greater numbers of stony coral species, 56 stations had

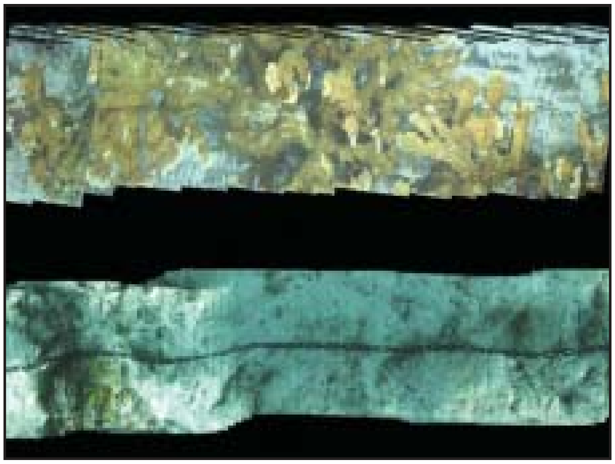


Figure 146. Changes in elkhorn coral cover at West Sambo, 1996 above and 2001 below (Photo: EPA/FKNMS Coral Reef Monitoring Project funded by EPA, UNCW, and NOAA).

fewer species, and 35 stations remained unchanged (Jaap *et al.* 2001).

In addition to coral cover, recruitment of stony corals to the Florida Keys ecosystem is a basic measure of overall community health. Relationships between coral cover, recruitment, and juvenile mortality are assessed at six sites in both fully protected Sanctuary zones and in reference areas (Aronson *et al.* 2001). Differences in coral recruitment have been seen among all sites over two years. More important, perhaps, is that juvenile mortality was greatest at shallow stations in the first year (1998) which coincided with a direct strike from Hurricane Georges in the Lower Keys. UNCW/NURC rapid assessment monitoring of benthic communities indicated no significant differences in juvenile coral density by habitat type and region in 2000 (Miller *et al.* 2001).

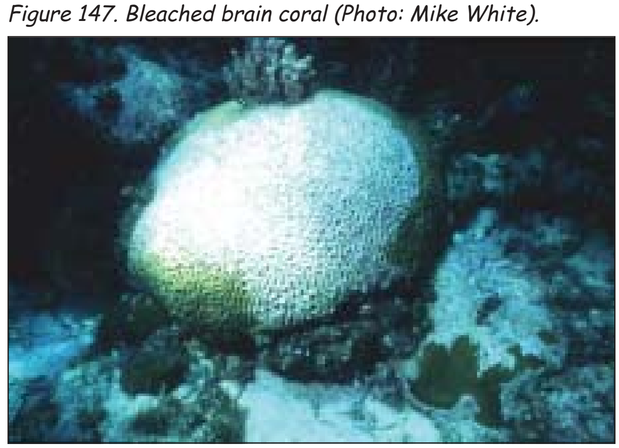
Increasingly, coral diseases threaten the overall health and vitality of reef systems in the Florida Keys. However, only three of ten presumptive or purported pathogens have been positively identified (Richardson 1998). The Coral Reef/Hardbottom Monitoring Project documented increases in the number of stations with diseased coral, the number of coral species with disease, and the number of presumptive diseases (Jaap *et al.* 2001). In 1998, a second ongoing coral disease etiology and monitoring program documented regional differences in the incidence of disease, with the highest concentration of coral diseases near Key West and in the Lower Keys. Significant seasonal increases in diseases were also noted in these regions (Mueller *et al.* 2001). Back reef areas showed the highest prevalence of disease. These areas are dominated by elkhorn coral, which is susceptible to specific disease conditions (Mueller *et al.* 2001, Fig. 146). Aspergillosis, a fungal disease that targets the sea fan (*Gorgonia ventalina*), was the most commonly reported disease Sanctuary-wide during these surveys (Mueller *et al.* 2001).

In addition to confirmed and purported coral diseases, coral bleaching impacts the Sanctuary's reefs (Fig. 147). Over the past 20 years, bleaching events have increased in both frequency and duration (Hoegh-Guldberg 1999, Jaap 1990). Massive coral bleaching was first recorded in 1983 along the outer reef tract of the Lower Keys. Shallow fore reef habitats were most affected (Causey in press). This event was preceded by periods of low wind and high air temperature, contributing to localized increased water temperature.

Massive bleaching occurred again in July 1987 following doldrum-like weather conditions. This time, the outer reefs throughout the Florida Keys were afflicted, and secondary impacts such as coral disease were observed. Then in July 1990, a massive bleaching event occurred Keys-wide. Inshore reefs bleached for the first time, and mortality of blade fire corals (*Millepora complanata*) reached over 65% on the shallow crest of Looe Key Reef in the Lower Keys (Causey in press).

Bleaching has both expanded and intensified in the last decade. Another massive episode in 1997 targeted both the inshore and offshore reefs. Before the reefs could adequately recover, lingering high water temperatures and a particularly strong El Niño event caused yet another bleaching in 1998.

Figure 147. Bleached brain coral (Photo: Mike White).



This time, the blade fire coral suffered 80-90% mortality (W. Jaap pers. comm.), and has remained low in abundance throughout most of the area. There have been similar bleaching observations regionally and internationally since 1987, and it is widely recognized that 1997 and 1998 were the worst years on record.

While it is difficult to enumerate the exact causes of coral mortality from any given perturbation, coral bleaching is undoubtedly responsible for part of the dramatic declines in stony coral cover observed Sanctuary-wide in the last five years (Causey pers. obs.). Observations from the research community reinforce the results from several monitoring programs that show declines in coral health. This highlights the importance of continued monitoring. Empirical cause-and-effect studies might provide additional methods to alleviate these impacts and improve overall reef health.

Along the southeastern shoreline, there is little long-term data on abundance and/or cover for benthic reef components. The predominant information on status and trends is anecdotal. However, some reefs appear healthy when compared to historical information and personal recollections. Bleaching has been observed over the years along the southeastern reefs at a comparable level to the Florida Keys.

There is no information available at this time on the status of corals and benthic communities at the Florida Middle Grounds.

Marine Algae, Other Plants, and Benthic Cover – Ninety species of marine macroalgae have been identified from coral reefs within the FKNMS (Littler *et al*. 1986). Additionally, there are seven species of seagrasses (Fourqurean *et al*. 2002) in the region. Six species are common throughout South Florida (Fig. 148), whereas one endemic species of seagrass is only found in the northern part of Biscayne Bay. Three species of mangrove also grow in Florida (Mote Marine Laboratory 2002).

Benthic monitoring under the Sanctuary's Zone Monitoring Program indicates algae and attached invertebrate populations (sponges and soft corals) fluctuate widely between seasons and years (Aronson *et al.* 2001). As with coral communities, some of this variability can be attributed to storms around the Florida Keys in 1998 and 1999.

Figure 148. Seagrass meadow at Indian River Lagoon on Florida's eastern coast (Photo: South Florida Water Management District).

Functional group cover analyses from Jaap *et al.* (2001) show a slight increase in macroalgal cover in all regions of the Florida Keys between 1996 and 2000 and indicate a general decrease in sponge and soft coral cover. Miller *et al.* (1999) found algae dominated all sites, with average cover generally above 75% in the Keys and above 50% in the Dry Tortugas region (2000). At deeper sites, predominant algal functional groups were fine and thick turf algae, brown frondose algae, green calcareous algae (mainly *Halimeda* spp.), and crustose coralline algae. Crustose coralline algae and green calcareous algae comprised a greater proportion of total algal cover at shallower sites than at deeper sites. In the Dry Tortugas, algal cover was mostly green calcareous algae and two genera of brown frondose algae.

In addition, sponge and soft coral coverages were minor (generally less than 10%) at shallow and deeper sites in the Keys (Miller *et al.* 1999) and generally low in the Dry Tortugas region (less than 20%) (Miller *et al.* 2000). Overall, variability is high across all regions for sponge cover (Miller *et al.* 2001). Likewise, analyses of benthic composition between fully protected zones and reference areas in the Sanctuary indicate that changes ob-

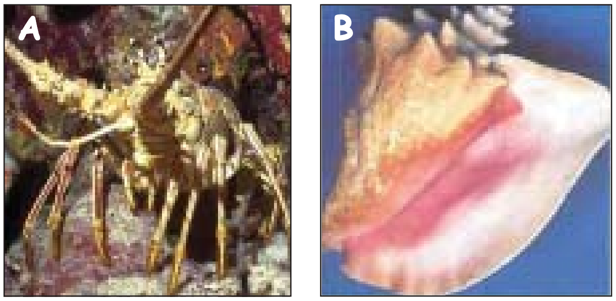


Fig. 149. A. Caribbean spiny lobster (Photo: Roberto Sozzani); B. queen conch (Photo: Caribbean Fishery Management Council).

served cannot be attributed to recent protection from fishing, but are likely a result of the initial biased selection of one of the zone types (Miller *et al.* 2001).

At least one species of seagrass was present at over 80% of the FKNMS stations monitored under the Water Quality Protection Program, indicating a coverage of approximately 12,800 km^2 of seagrass beds within the 17,000 km^2 study area that lies within and adjacent to the Sanctuary (Fourqurean *et al.* 1999). The primary species of seagrasses within the Sanctuary are turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), shoal grass (*Halodule wrightii*), and balloon grass (*Halophila decipiens*).

As with coral communities, there is currently no comprehensive data available on algae or seagrasses from Florida's southeastern coast or Middle Grounds regions.

Mobile invertebrates – Diverse groups of invertebrates have been identified in the Florida Keys, including 117 species of sponges (Levy *et al.* 1996), 89 species of polychaete worms (Levy *et al.* 1996), more than 1,400 species of mollusks (Mikkelsen and Bieler 2000), 371 species of crustaceans (Levy *et al.* 1996), and 82 species of echinoderms (Hendler *et al.* 1995).

The focus of recent monitoring efforts has been on large mobile invertebrates such as the Caribbean spiny lobster (*Panulirus argus*) and queen conch (Fig. 149). Both have been moni-tored inside and outside of the Sanctuary's fully protected zones under the zone monitoring pro-gram. The size of spiny lobsters are also being tracked in the Dry Tortugas, where National Park designation eliminated this fishery several years ago. Since the closure, individual lobsters have grown larger there than in the remainder of the Florida Keys.

Legal-sized spiny lobsters continue to be larger and more abundant in fully protected zones than in reference sites of comparable habitat. In the sanctuary preservation areas (SPAs), they average above legal minimum size. At reference sites, they remain below legal size (Cox *et al.* 2001). This is particularly true in the Western Sambo Ecological Reserve, where the average size has been significantly larger than in reference areas during both the open and closed fishing seasons (C. Cox pers. comm., Gregory 2001). Catch rates (number of lobsters per trap) are also higher within the Western Sambo Ecological Reserve than within two adjacent fished areas (Gregory 2001).

Queen conch populations have remained low in the last decade, despite a ban on commercial and recreational fishing since the mid-1980s. An intensive monitoring program directed by the Florida Fish and Wildlife Conservation Commission's Florida Marine Research Institute (FWC/FMRI) continues to find no significant differences in conch aggregation sizes, density, or abundance between fully protected zones and reference sites in the Sanctuary (Glazer 2001). Attempts to supplement wild populations with laboratory-reared stock and experiments to improve reproductive output are underway to address the long-term demise of this species.

Additional monitoring and some experimental research are focused on sea urchin populations within the Florida Keys. Various scientists speculate urchins play a critical role in structuring reef

Figure 150. Selected fish species that are numerically dominant or account for much of the biomass on Florida Keys reefs (Photos: FKNMS).

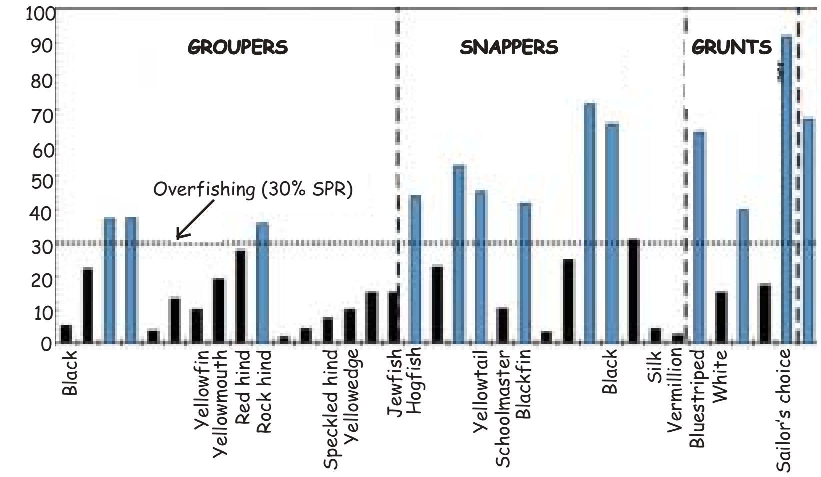


Figure 151. Estimated percent Spawning Potential Ratios (SPR%) for 35 species of reef fish comprised of groupers, snappers, grunts, hogfish, and great barracuda. Black bars indicate stock "overfishing" and blue bars indicate the stock is above the 30% SPR U.S. Federal standard (Modified from Ault et al. *1998).*

communities by acting as key herbivores, keeping algae in check so adult corals can continue to grow and new corals may recruit to appropriate substrate. Reductions in the sea urchin population due to a massive, Caribbean-wide die-off in 1983 and relatively poor recovery of populations since then have been confirmed by two separate teams in the zone monitoring program (Fogarty and Enstrom 2001, Miller *et al*. 2001). Both document very low abundances of sea urchins, especially the long-spined sea urchin. Two research efforts underway in the Sanctuary are exploring viable means of restoring populations of this keystone species to coral reef habitats.

Fish – Considerable scientific attention has been paid to fish species of the Florida Keys over the last several decades prior to the designation of the Sanctuary and its fully protected zones. Starck (1968) identified 517 fish species from the Florida Keys, including over 389 reef fish. Additional surveys have been conducted since 1979, documenting species composition, abundance, frequency, and size estimates (Bohnsack *et al.* 1999). Between 1979-1998 a total of 263 reef fish taxa representing 54 families were observed (Bohnsack *et al.* 1999). Numerically, over half (59%) of all fish were from just 10 species (Fig. 150). The majority of total fish biomass was comprised of just a few species (Bohnsack *et al.* 1999).

Figure 152. Gray snapper have benefitted from the fully protected zones (Photo: FKNMS).

The numerically dominant fishes observed were bluehead wrasse (*Thalassoma bifasciatum*), bicolor damselfish (*Stegastes partitus*), tomtate (*Haemulon aurolineatum*), sergeant major (*Abudefduf saxatilis*), striped parrotfish (*Scarus croicensis*), yellowtail snapper (*Ocyurus chysurus*), bluestriped grunt (*Haemulon sciurus*), white grunt (*Haemulon plumieri*), masked goby (*Coryphopterus personatus*), and French grunt (*Haemulon flavolineatum*). Other species accounting for most of the observed biomass were tarpon (*Megalops atlanticus*), barracuda (*Sphyraena barracuda*), gray snapper, Bermuda chub (*Kyphosus sectatrix*), stoplight parrotfish (*Sparisoma viride*), smallmouth grunt (*Haemulon chrysargyreum*), and yellow goatfish (*Mulloidichthys martinicus*) (Bohnsack *et al.* 1999).

Trends in spatial distribution and differences in populations over time are also noted. In most cases, relatively few fish of legal, harvestable size were seen. This is consistent with other studies indicating reef fish are highly exploited. Based on federal standards (Ault *et al.* 1998), 13 of 16 species of groupers, seven of 13 snappers, one wrasse, and two of five grunts are overfished in the Florida Keys (Fig. 151). Non-sustainable fisheries practices are likely changing trophic interactions on reefs, with secondary effects such as reduced reproductive capacity (PDT 1990) and shifts in ecosystem structure and function.

Despite declines elsewhere in the Sanctuary, fish numbers of some economically important species are increasing somewhat in the fully protected zones. Analyses of three years of reef fish data show average densities (number of individuals per sample) for the exploited fish species – gray snapper (*Lutjanus griseus*, Fig. 152), yellowtail

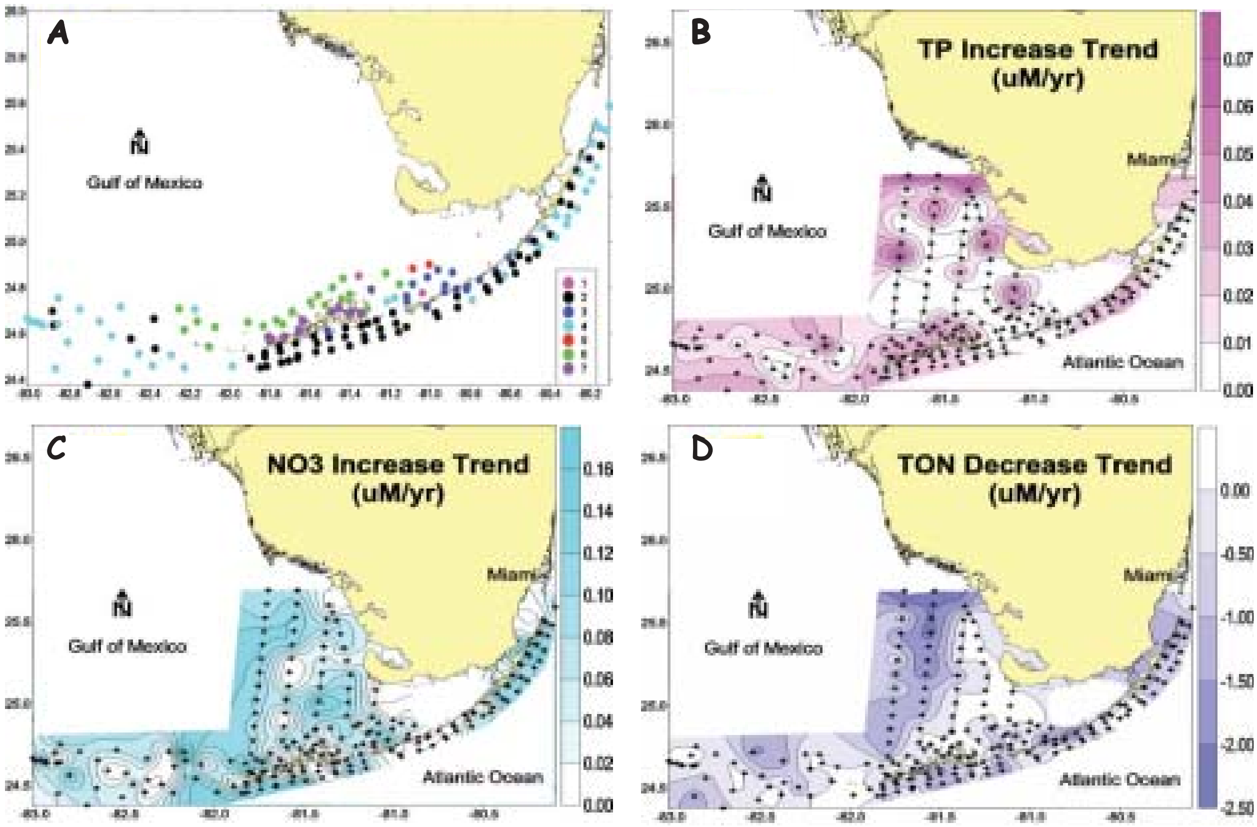


Figure 153. A. Map of water quality stations in FKNMS that are clustered according to statistical similarities in water quality parameters. B. Total phosphus (TP) trends in FKNMS, 1995-2000. Note significant increases in the Dry Tortugas, Marquesas Keys, Lower Keys, and portions of the Middle and Upper Keys. C. Nitrate (NO_3) trends in FKNMS, 1995-2000. Increases occurred in the Southwest Florida Shelf, Dry Tortugas, Marquesas Keys, and Lower and Upper Keys. D Total organic nitrogen (TON) trends in FKNMS, 1995-2000. A moderate decrease in TON occurred in some areas, in contrast to increases in TP and NO_3. (Source: Jones and Boyer 2001).

snapper (*Ocyurus chrysurus*), and grouper (several economically important species were combined) – are higher in the SPAs than in fished reference sites (Bohnsack *et al.* 2001). Complementing this data is a trend in increasing average abundance of three species of snapper (gray snapper, schoolmaster, and yellowtail snapper) at sites monitored by Reef Environmental Education Foundation (REEF) volunteers before and after designation of the fully protected zones (Pattengill-Semmens 2001).

Water Quality – Reduced salinity, agricultural and industrial chemical contamination, turbidity, and high nutrients possibly from sewage, upwelling, or groundwater have all impacted water quality to some degree in Southeast Florida, Florida Bay, and the Florida Keys. Ocean outfalls along the coast introduce millions of gallons of secondary sewage to coastal waters, adding nutrients. Eutrophication of nearshore waters (a result of excess nutrients) is a documented problem in the Keys. Given these anthropogenic impacts and the importance of also fully understanding natural variability, long-term water quality monitoring is critical for the entire South Florida region. Water quality has been monitored at fixed stations in the FKNMS since 1995 as part of the Water Quality Protection Program (FKNMS WQPP 2002). Results to date indicate dissolved oxygen, total organic nitrogen, and total organic carbon are higher in surface waters, while salinity, turbidity, nitrite, nitrate, ammonium, and total phosphorus are higher in bottom waters. Geographical differences include higher nutrient concentrations in the Middle and Lower Keys than in the Upper Keys and Dry Tortugas regions. Generally, declining inshore to offshore trends along transects across Hawk Channel have been noted for nitrate, ammonium, silicate, total organic carbon and nitrogen, and turbidity (Jones and Boyer 2001).

Stations along passes between the Keys had higher nutrient concentrations, phytoplankton biomass, and turbidity than stations located off the Keys. Although these differences were small, the two shore types support different benthic communities, which may reflect long-term effects of water quality on community composition. Using a multivariate statistical approach, these stations were regrouped according to water quality. This resulted in seven clusters of stations with different water quality characteristics (Fig. 153), giving a functional zonation of Sanctuary water quality.

Probably the most interesting results are temporal trends in concentrations of total phosphorus, nitrate, and total organic nitrogen for much of the Sanctuary. There have been significant increases in total phosphorus for the Dry Tortugas, Marquesas Keys, Lower Keys, and portions of the Middle and Upper Keys. No trend in total phosphorus has been observed in Florida Bay or in areas of the Sanctuary most influenced by transport of Bay waters, and there was no concurrent increase in the concentration of chlorophyll *a*, a measure of phytoplankton in the water column. There were large increases in nitrates, which appeared to be seasonal. Most of the increases occurred in the Southwest Florida Shelf, Dry Tortugas, Marquesas Keys, and the Lower and Upper Keys. By contrast, total organic nitrogen decreased modestly at many sites. Most of the decreases occurred in the Southwest Florida Shelf, the Sluiceway, and the Lower and Upper Keys. It is possible that these trends are driven by regional circulation patterns arising from the Loop and Florida Currents.

Coastal Populations and Reef Economics

Much of South Florida is urban and its resident population continues to expand. A total of 5.09 million people resided in the four-county area of South Florida (Miami-Dade, Broward, Palm Beach, and Monroe Counties) in 2000, an increase of 23.1% in the past 10 years (U.S. Bureau of the Census 2002). Of this total, 2.25 million live in Miami-Dade, 80,000 live in Monroe (Florida Keys), 1.13 million in Palm Beach, and 1.62 million in Broward counties.

Figure 154. Visitors and residents at a South Florida beach (Photo: NOS Photo Gallery).

Due to its climate and natural resources, South Florida draws millions of seasonal and temporary visitors (Fig. 154). Miami-Dade County receives a daily summer average of 240,000 seasonal and temporary visitors and a daily winter average of 308,000 visitors. Each day, Broward County receives between 140,000-320,000 visitors, depending on the season; Palm Beach County receives 73,000-183,000 visitors; and Monroe County receives 30,000-36,000 visitors (Johns *et al.* 2001). Including these visitors gives Miami-Dade, Broward, Palm Beach, and Monroe Counties, a functional population[145] of 2.49-2.56 million, 1.76-1.94 million, 1.2-1.3 million, and 110,000-116,000, respectively.

Johns *et al.* (2001) estimated market economic contributions and non-market economic user values for recreational use of artificial and natural reefs. In the four-county South Florida region, residents and visitors spent 18.2 million person-days fishing, diving, and viewing natural coral reefs from glass-bottom boats, yielding an annual non-market economic use value estimate of nearly $228 million. This annual value[146] yields an estimate of the asset value of the natural reefs at $7.6 billion. Additional information on the economic impact of tourism has been summarized in Table 15.

*Table 15. Recreation and tourism on natural reefs in Southeast Florida. *Totals for these economic values are likely to be underestimated, because the data do not include inter-regional flows (Source: Johns et al. 2001).*

County	Person-Days (millions)	Number of Jobs*	Income (millions)*	Output/Sales (millions)*	User Value (millions)	Asset Value (billions)
Broward	5.5	19,000	$547	$1,100	$83.6	$2.8
Miami-Dade	6.2	13,000	$419	$878	$47.0	$1.6
Monroe	3.6	8,000	$106	$363	$55.0	$1.8
Palm Beach	2.8	4,500	$142	$357	$42.0	$1.4
Totals	18.1	44,500	$1,214	$2,706	$227.6	$7.6

In addition to supporting tourism in the region, coral reefs play an important role in maintaining Florida's commercial and recreational fisheries. In 2000, Monroe

145 Functional populations include the number of people in a given area, on a given day, which demand local services (e.g., freshwater, sewage and solid waste disposal, electricity, transporation services). This number of people includes not only the permanent residents of an area, but also seasonal and temporary visitors.

146 In calculating this value, it was capitalized at a real interest rate (i.e., 'interest rate net of inflation' of 3% into perpetuity).

Figure 155. Approximately 900,000 people dive or snorkel in the Florida Keys each year (Photo: Paige Gill).

County commercial fishermen earned $53.2 million in ex-vessel revenues (FWCC 2000). Since 40-60% of the commercial catch in this county is related to coral reefs, it can be estimated that the reef-related catch was worth $22-32 million. Subsequently, this generated $35-52 million in local sales/output, $22-33 million in income, and 1,550-2,300 jobs (R. Leeworthy pers. comm.).

Recreational fisheries on natural reefs generated $171 million in output/sales, $44 million in income, and over 3,100 jobs. These totals are included in Table 15. In 2000-2001, commercial and recreational fisheries dependent on the natural reefs of the Florida Keys alone generated $206-223 million in output/sales, $66-77 million in income, and supported 4,650-5,400 jobs in Monroe County.

Environmental Pressures on Coral Reefs

Human Stresses – Humans can inadvertently alter physical characteristics of the reef environment, further stressing an ecosystem already combatting the broader stresses of natural variability and global climate change. Impact from human activities is likely greater in the Keys and along the southeastern coast than in the Middle Grounds. Due to its offshore location, the Middle Grounds has been somewhat protected, particularly from pollutants.

In the Florida Keys, the greatest immediate pressure is from the three million annual visitors (Leeworthy and Vanasse 1999) and the 80,000 year-round residents. The population of Monroe County has grown 160% during the past 40 years, a 50,000 resident increase. Visits to the Florida Keys increased by 15% in the two-year period from 1995-96 to 1997-98, and averages 46,500-58,700 visitors on any given day during the winter tourist season (Leeworthy and Vanasse 1999). In 1995-1996, over 65% of visitors to the Florida Keys participated in water-based activities, 31% of which were snorkeling and SCUBA diving (Leeworthy and Wiley 1996, Fig. 155). Since 1965, the number of registered private vessels has increased over six-fold (DoC 1996, Fig. 146).

Damage by humans to hundreds of square kilometers of reef, seagrass, and related habitat over the last 30 years has been documented for some time in the Florida Keys. Boat groundings on coral, seagrasses, and hardbottom areas, propeller scarring of seagrass, accumulation of debris, breaking and damaging corals with ship anchors, using destructive fishing methods, and divers and snorkelers standing on corals have all been documented in various places.

Boat propellers have permanently damaged over 121 km^2 of seagrasses. Over 650 small boat groundings were reported in the Sanctuary in 2000 alone, with 158 of these affecting seagrass and 22 impacting coral reef habitats. Large ships have been responsible for damaging or destroying over 80,000 m^2 of coral reef habitat in the Sanctuary.

Wastewater and stormwater treatment and solid waste disposal facilities in the Keys are highly inadequate, having a direct impact on water quality. However, some solutions to water quality problems are being implemented. One of the larger ocean outfalls off Key West that delivered approximately seven million gallons a day to the sea was recently replaced with a deep-well injection system (more than 914 m deep and below a containment layer) for treated effluent. Before injection, the effluent is

Figure 157. Currently, there are over 106,000 boats registered in south Florida (Photo: FKNMS).

treated according to USEPA Advanced Wastewater Treatment standards.

Another indirect impact is altered freshwater flow into coastal waters. The South Florida Water Management District has responsibility for managing the flow and release of freshwater to the ocean through an extensive system of canals and locks. In Florida Bay, reduced freshwater flow from water management practices in South Florida has been associated with increased plankton blooms (eutrophication), sponge and seagrass die-offs, and fish kills. Since Florida Bay and nearshore waters provide critical nursery and juvenile habitat for a variety of reef species, the declines seen in these areas indirectly affect the overall health and structure of offshore coral reefs in the Florida Keys. In addition, to control flooding, millions of gallons of fresh water have periodically been released into the canals and near-shore waters of South Florida, creating problems for marine communities.

The highly urbanized coastal region along Florida's southeastern coast puts its coral reefs under varied and chronic stress. During good weather, both recreational and commercial boating and fishing are very heavy on these reefs. The nearby Miami, Port Everglades, and Palm Beach ports handle cruise and container ships, oil tankers, and military vessels. In the past ten years, a number of moderate to severe large vessel groundings in Southeastern Florida have damaged the reef system (Fig. 157). Signs of anchor damage are also routinely seen. Four other large-vessel groundings have impacted areas of nearby Biscayne National Park.

Serial overfishing (Ault *et al.* 1998) throughout South Florida has dramatically altered reef fish and other animal populations, contributing to an imbalance in relationships critical to sustaining coral reef diversity. In Biscayne National Park, 26 of 34 fish species, or 77% of the fish stocks that were examined were overfished (Ault *et al.* 2001). In addition, certain types of fishing gear negatively impact reefs in Southeastern Florida.

Reef tracts off Boca Raton and Sunny Isles have been destroyed by dredging for beach renourishment, channel deepening, and channel maintenance. Chronic turbidity and silt deposition from dredging and similar activities impact water quality, indirectly affecting the reefs. These activities smother sessile invertebrates, resulting in

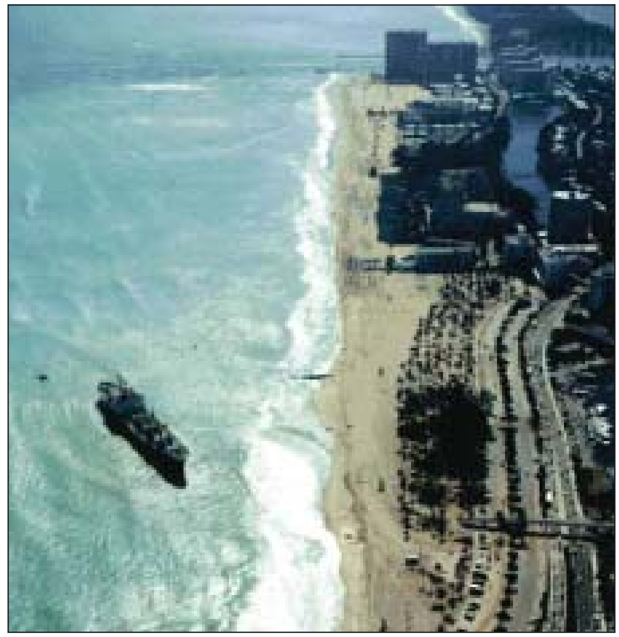


Figure 157. The M/V Firat grounded offshore of Fort Lauderdale, Florida (Photo: Greg McIntosh).

barren areas. Fiber optic cables were deployed across reefs in some areas, causing abrasion and detachment of corals and sponges (Jaap 2000).

Introduced, competitive species add additional stress. Within the past decade, several alien species have been identified on Florida Keys reefs. At least eight species of marine mollusks have been introduced into South Florida and are expanding their range. Non-native marine crustaceans are equally diverse and include six crab species, five shrimp species, three barnacles, four isopods, and one tanaid. Most of these species are foreign to North American waters and were introduced through ship hull fouling or ballast water dumping (USGS 2002).

The majority of Florida's marine fish introductions have come from released aquarium fish, with occasional reports from divers of various exotic species living among native reef fish. For example, the Indo-Pacific lionfish (*Pterois volitans*) has been sighted on South Florida reefs (Courtney 1995). Another popular aquarium fish, the Pacific batfish (*Platax orbicularus*), was observed off the Upper Keys; two specimens were removed and delivered to the New England Aquarium (B. Keller pers. comm.).

Natural Variability – In addition to the myriad of human impacts affecting coral reef health in Florida, natural environmental variability affects these habitats. Principal natural environmental

Figure 158. Several hurricanes have recently hit Florida, impacting its reefs (Photo: South Florida Water Management District).

impacts include hurricanes (Fig. 158), severe storms, winter cold fronts, cold-water upwelling, and ground water effects. Under normal conditions, corals and associated reef organisms tolerate a certain level of environmental stress and recover or acclimatize to sporadic events such as temperature variation or storms. The added human impacts and stresses may be prolonging the time needed as well as the ability of these organisms and systems to recover from large-scale climate fluctuations and other global changes.

Current Conservation Management

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 state-wide.

Mapping efforts were undertaken in the Sanctuary in the 1990s. FWC/FMRI and NOAA published digital benthic habitat maps for the Florida Keys in 1998 (FMRI/NOAA 1998, Fig. 159). 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 suggest 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 not as well studied. In 1999, Nova Southeastern University's National Coral Reef Institute (NSU/NCRI) and the Broward County Department of Planning and Environmental Protection initiated mapping of Broward County reefs. At this time, there is no comparable mapping program in Palm Beach and Miami-Dade Counties.

Improved mapping has resulted from aerial photos of near-shore areas and laser-based bathymetry of the three reef tracts off Southeastern Florida for specific projects. For example, detailed LADS (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.

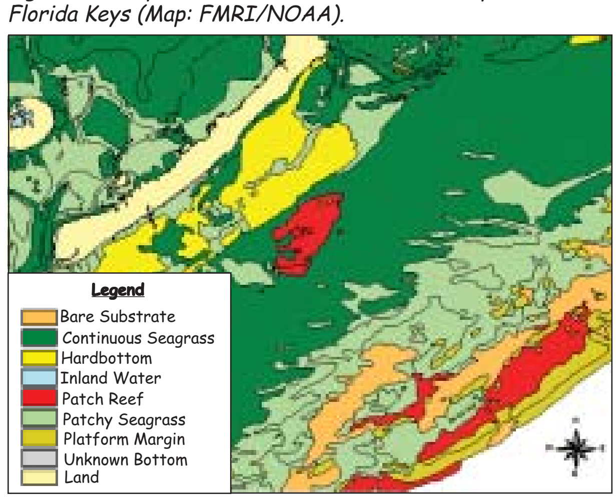
Estimates of benthic cover are available from some monitoring programs. There is a general reef distribution map in Jaap and Hallock (1990).

No mapping of the Florida Middle Grounds has been conducted to date.

Monitoring, Assessments, and Research – In the Florida Keys National Marine Sanctuary, 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 re-

Figure 159. A portion of the benthic habitat map of the Florida Keys (Map: FMRI/NOAA).



search foundations, environmental organizations, and independent researchers. The Sanctuary facilitates and coordinates research by registering researchers through a permitting system, recruiting institutions for priority research activities, overseeing data management, and disseminating findings to the scientific community and the public.

The Water Quality Protection Program (WQPP), funded by the USEPA and recently, NOAA, is the most comprehensive, long-term monitoring program in the Florida Keys. Begun in 1994, it monitors three components: water quality, seagrasses, and corals/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 for measuring salinity, temperature, dissolved oxygen, turbidity, relative fluorescence, and light attenuation. Water chemistry includes nitrate, nitrite, ammonium, dissolved inorganic nitrogen, and soluble reactive phosphate. Concentrations of total organic nitrogen, total organic carbon, total phosphorus, and silicate are also measured, along with chlorophyll *a* and alkaline phosphatase activity (Jones and Boyer 2001).

Seagrass monitoring under the WQPP identifies the distribution and abundance of seagrasses within the Sanctuary and tracks changes over time. Quarterly monitoring is conducted at 30 fixed stations and annual monitoring occurs at 206 to 336 randomly-selected sites (Fourqurean *et al.* 2001, WQPP 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 Coral Reef/Hardbottom Monitoring Project (CRMP 2002) tracks the status and trends of coral and hardbottom communities throughout the Sanctuary (Jaap *et al.* 2001, Fig 160). 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.

In addition to the WQPP, a 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 values 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.

Figure 160. Photo-monitoring of corals within the FKNMS (Photo: Mike White).

Lastly, continuous monitoring of certain physical parameters of seawater and ocean condition is recorded by instruments (C-MAN stations) installed along the Florida Reef Tract as part of the SEAKEYS 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 it to satellites, where it is converted to near real-time reports available on the Internet. For the past ten years the Sanctuary has maintained a network of 27 thermographs that record water temperature every two hours, located both inshore and offshore throughout the Keys.

As baselines are being documented, Sanctuary 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 understand-

Figure 161. Coral reef monitoring along Florida's southeastern coast (Photo: NCRI).

ing 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, so that changes occurring as a result of water management regimes and restoration can be detected.

Figure 162. Detail of an artificial reef that is being used by NCRI to study reef restoration techniques (Photo: NCRI).

Along Florida's southeastern coast, much of the present monitoring originated as impact and mitigation studies for projects that had adverse impacts to specific sites (dredging, ship groundings, pipeline and cable deployments, and beach renourishment). In the past, such studies have been of limited duration (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 23 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 (Fig. 161). 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, Light 2001, C. Avila pers. comm.).

However, there is a concerted effort of NSU/NCRI scientists to complete a baseline survey of reef fishes off Broward County (Ettinger *et al.* 2001, Harttung *et al.* 2001). Initiated in 1998, this NOAA-funded survey is recording fishes on the edges and crests of the three major reef lines. At this time, more than 600 point-counts have been completed, and the full survey will be completed by mid-2002. In addition, during summer 2001, NSU/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 min random swim) (Baron *et al.* 2001). Broward County now has a database comprised of more than 1000 visual censuses from the shore to 30 m for reef fish.

Researchers at NSU/NCRI are also currently involved in a multivariate, hypothesis-driven study that looks at the interaction of fish, transplanted corals, coral recruits, and potential coral attractants or optimal substrates (Fig. 162). Research variables include four potentially different fish assemblages (determined by reef complexity) and biofilm and coral recruitment on settlement plates of 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.

The Florida Middle Grounds do not have any ongoing, formal monitoring programs at this time. Overall, the development of a comprehensive monitoring program for the reefs of southeastern Florida and the Florida Middle Grounds would provide a better understanding of current conditions for fish and corals in these regions and would promote more effective management.

MPAs and Fully Protected Reserves – As with monitoring, assessment, and research programs, coral reef conservation and management through the designation and implementation of marine protected areas (MPAs) varies widely. The largest and best-known MPA in Florida, the Florida Keys

National Marine Sanctuary, was designated in 1990, 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 otherwise altering the seabed, and 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, in 1997 the Sanctuary instituted a network of marine zones 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 (Fig. 163). 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%.

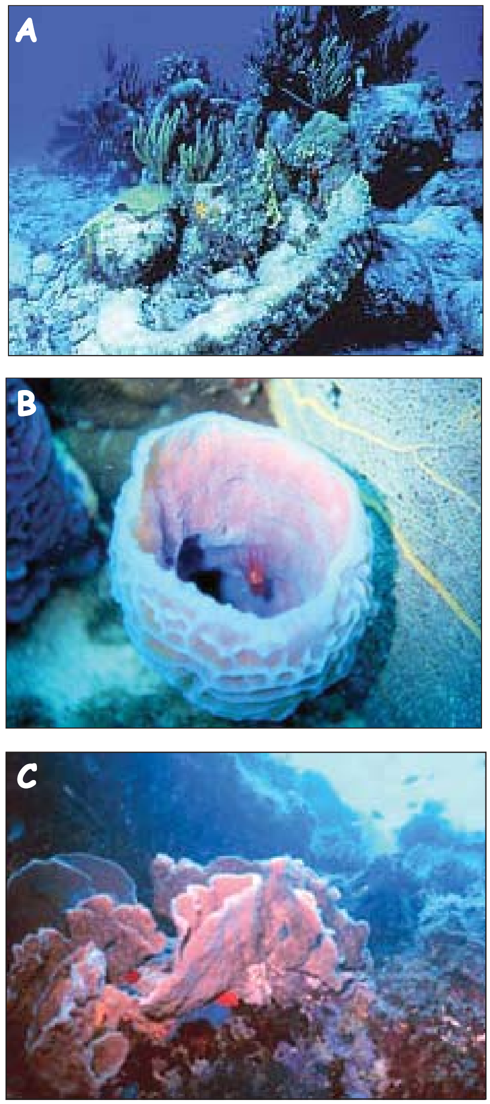


Figure 163. Recently established MPAs located offshore of Florida: A. Tortugas Ecological Reserve B. Madison-Swanson Spawning Site and C. Steamboat Lumps Spawning Site (Photos: NOAA Photo Library and NPS).

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 National Park Service. 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 National Park's Research Natural Area fully protect near-shore to deep reef habitats of the Tortugas region and form the largest, permanent marine reserve in the United States.

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.

Figure 164. Mangrove prop roots serve as important nursery sites for certain fish species (Photo: Matt Kendall).

Biscayne National Park 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 National Park Service is concerned about degradation of Park 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 provide 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 disturbance. In addition, the Park 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 the Great White Heron National Wildlife Refuge overlap with portions of the Florida Keys National Marine Sanctuary 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 (400,000 acres) of lush seagrass beds, reef tract, patch reefs, hardbottom community, and pristine mangrove islets. A cooperative agreement with the 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 to ensure their continued conservation. The U.S. Fish and Wildlife Service, as administrators of the National Wildlife Refuge System, works cooperatively with the State and the Sanctuary for the protection of these sites.

Of the dozen or so 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 (61,531 acres) and has 461 km^2 of coral reefs, seagrass beds, and mangrove swamps. Lignumvitae 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.

Reefs off the southeastern coast and the banks of the Middle Grounds have some protection through various MPAs, but neither region is as comprehensively protected tas the Florida Keys. North of Vero Beach, the Oculina Bank Habitat Area of Particular Concern (HAPC) was established in 1984 and is currently under the management of NOAA's National Marine Fisheries Service (NMFS) and the South Atlantic Fishery Management Council. The HAPC runs along the central Florida eastern coast, from Ft. Pierce to Cape Canaveral, and protects deep-water pinnacles of ivory coral (*Oculina* spp.) This habitat has been identified as easily impacted by fishing activities, including destruction by dredges, trawlers, and long-line fishing gear.

The Madison-Swanson and Steamboat Lumps Spawning Sites were established in June 2000 under authority of the Magnuson-Stevens Fisheries Conservation and Management Act and will be managed by NMFS and the Gulf of Mexico Fishery Management Council. These MPAs, located offshore on the West Florida shelf, were created to protect spawning aggregations of gag (*Mycteroperca microlepis*) as well as other reef and pelagic fish species from fishing activities. Deepwater habitats are also protected from fishery-related impacts. These areas are closed to all fishing for a period of four years in order to evaluate the effects of fishing on spawning aggregations.

The Florida Middle Grounds HAPC was established in 1984 to protect this deeper coral habitat. Located approximately 70 nautical miles to the northwest of Clearwater, FL, the HAPC prohibits the use of several types of commercial gear, including fish traps, to protect and maintain fish stocks. The HAPC is under the management of NMFS and the Gulf of Mexico Fishery Management Council.

Gaps in Monitoring and Conservation Capacity

Current monitoring in the Florida Keys National Marine Sanctuary has largely focused on detecting changes within the fully protected zones and determining Sanctuary-wide status and trends of water quality, seagrasses, and corals. Some trends are beginning to show, providing a source of hypotheses to be tested. Continued monitoring is critical. These data will facilitate detecting long-term changes in communities both locally and ecosystem-wide.

Reef monitoring programs in southeastern Florida are limited by a near total lack of comprehensive inventories and assessments of marine communities in this area. Baseline assessments with monitoring programs at sites located off each of the counties in the region are needed. 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 needs to be done to obtain a complete picture of the resident ichthyofauna. In addition, the fish below 30 m are poorly characterized and exploited by recreational fishers.

Likewise, the reef fish communities from seagrass and mangrove habitats of Port Everglades and the Intracoastal Waterway (ICW) remain a mystery. Given the high level of human activity in the area and since these are potentially important nursery sites (Leis 1991, Fig. 164), there is need for immediate clarification.

A formal monitoring program should also be instituted in the Florida Middle Grounds. Ideally, stations would be established based on the sites surveyed by Hopkins *et al.* in 1977. The ability to compare the area's current status with previous data would be helpful in detecting changes over time. To that end, video transects and methods comparable to the 1977 work should be employed.

The reefs along the southeast coast and the Middle Grounds banks should be fully mapped. The data should be consistent with state, national, and international programs, and should be rapidly disseminated for public consumption. A regional archive should be established.

Government Policies, Laws, and Legislation

When President George 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. Its authority, along with the 12 other national marine sanctuaries, is established under the National Marine Sanctuaries Act (NMSA) of 1972, 16 U.S.C. 1431 *et seq*., as amended. The Sanctuary is administered by NOAA under the Department of Commerce, and is managed jointly with the State of Florida under a co-trustee agreement because over half of the waters of the Sanctuary are state territorial waters. The co-trustee agreement commits the Sanctuary to a periodic review of the management plan; the first review will be in 2002.

In 1997, a comprehensive management plan for the Sanctuary was implemented. It contains ten action plans and associated strategies for conserving, protecting, and managing the significant natural and cultural resources of the Florida Keys marine environment.

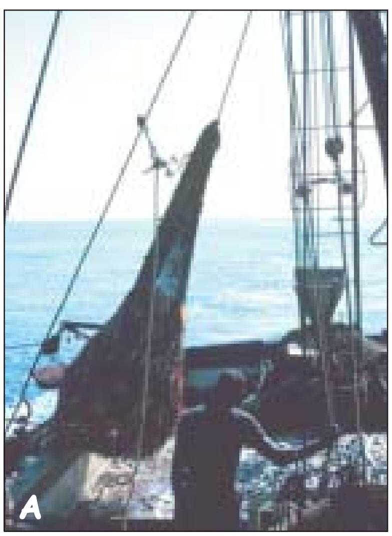
Largely non-regulatory, the strategies educate citizens and visitors, use volunteers to build stewardship for local marine resources, appropriately mark channels and waterways, install and maintain mooring buoys for vessel use, survey submerged cultural resources, and protect water quality. As described previously, the Sanctuary management plan also designated five types of marine zones to reduce pressures in heavily used areas, protect critical habitats and species, and separate use conflicts.

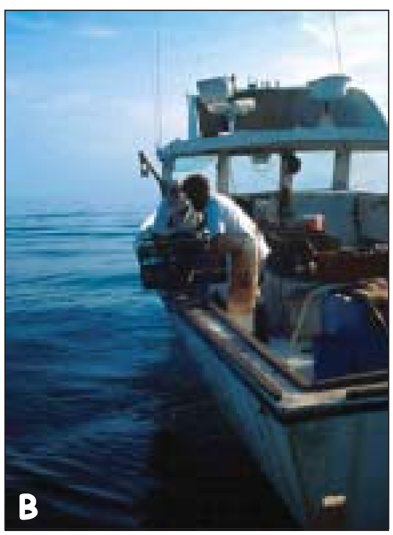
A total of 24 fully protected zones were implemented in 1997 and 2001, covering approximately 6% of the Sanctuary, but protect 65% of shallow bank reef habitats and about 10% of coral resources. Most of the smaller zones (sanctuary preservation areas) are located along the offshore reef tracts and encompass 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 Research and Monitoring Action Plan of the Sanctuary.

Commercial fishing remains one of the largest industries in the Florida Keys (Fig. 165), 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, gear catch size restrictions. The State also collects landing information on approximately 400 kinds of fish, invertebrates, and plants to track trends in catch and to evaluate regulations (DoC 1996).

The reefs of southeastern Florida are in State territorial waters and protected from some impacts by State statutes and regulations. These include fishing regulations, dredging permits, and a statute protecting corals from harvest, sale, or destruction. Broward County has a small boat mooring program intended to reduce anchoring impacts on reefs.

Figure 165. Both shrimp (A) and lobster (B) fisheries are important industries in South Florida (Photo: Paige Gill, FKNMS and NOAA).





Conclusions and Recommendations

Overall, immediate action is needed to curtail alarming declines in coral reef condition throughout Florida. Local communities that are culturally and economically supported by coral reefs must employ management strategies and focus on alleviating controllable human impacts. For example, in southeastern Florida, the environmental impacts of fisheries, dredging, vessel anchorages, freshwater management, and nutrient input should receive attention to maximize protection to the reefs in this area. In the Florida Keys, solutions that address wastewater and stormwater problems, habitat degradation, and overfishing must be pursued.

At the regional level, elected officials and policymakers should work to conserve and protect watersheds, reduce emissions, and decrease energy use. Citizens, elected officials, and MPA managers must work together to improve water quality, minimize physical impacts to corals and seagrasses, employ sustainable fishing practices, reduce pollution, and save energy.

Globally, strict air pollution standards must be adopted, carbon dioxide emissions reduced, and renewable energy technologies employed to curb global warming trends. International policies on global climate change should be adopted and implemented. Comprehensive coral reef protection will ultimately require both proactive local steps and engaging leaders regionally and globally on climate change issues.