

close to oil refineries, storage facilities or shipping lanes frequented by oil tankers. These areas should have, as a minimum, a current oil/hazardous materials response plan in place.

Despite extensive oil and gas activity in Gulf of Mexico Continental Shelf waters and the fact that some of the other U.S. and Freely Associated States coral reef ecosystems are close to oil refineries, storage facilities or shipping lanes frequented by oil tankers, only managers from the Flower Garden Banks National Marine Sanctuary expressed moderate concerns over offshore oil and gas threats to coral reef systems (Table 1). Even though the Flower Garden Banks National Marine Sanctuary is located in the Gulf of Mexico, it is not close to oil refineries, storage facilities or shipping lanes frequented by oil tankers. The Flower Garden Banks National Marine Sanctuary is located in the Gulf of Mexico, it is not close to oil refineries, storage facilities or shipping lanes frequented by oil tankers. The Flower Garden Banks National Marine Sanctuary is located in the Gulf of Mexico, it is not close to oil refineries, storage facilities or shipping lanes frequented by oil tankers.

STATE OF CORAL REEF ECOSYSTEMS

The following subsections summarize by region what is now known about local reef characteristics, socioeconomic pressures and ecological impacts, condition of coral reef ecosystems, resource management and marine protected areas (MPAs), mapping and monitoring capacity. The information contained in this section is mostly from reports requested from and provided by the USCRTF Points of Contact representing the Governors of U.S. States and Territories. For more detail, readers are referred to the resulting nine Jurisdictional Reports, authored by 29 program managers and scientists, on the condition of their respective reef ecosystems are appended to the National Summary (see Appendices I-IX). Information contributed from over 75 experts and from a search of the literature was compiled and summarized by the authors for the National Summary, making the following sections an even more robust source of baseline information on the status and trends of coral reef ecosystems. In order of presentation in this section, summaries of the state of Western Atlantic and Caribbean State and Territorial reef ecosystems—Florida, Puerto Rico, and the USVI), the Flower Garden Banks National Marine Sanctuary and Navassa Island—appear first. Next, assessment reports on U.S. Pacific islands follow in order—Hawai'i, American Samoa, Guam, the CNMI, and the remaining remote reef systems under Federal protection. The Freely Associated States of Palau and the Federated States of Micronesia have been included and appear last, but a report is not available for the Marshall Islands. The Marshall Islands are known to have biologically diverse and extensive reefs covering an estimated 5,000 km² (Spalding *et al.* 2001). In 2001, the latter nations requested to be included in all USCRTF activities in light of their historical and current affinities with U.S. Pacific Territories; for this reason they were included. For an across-region comparison and summary on the condition of coral reef ecosystems, see the Recommendations and Conclusions section near the end of this report.

Florida⁴

Reef characterization. Florida's coral reefs are extensive, interspersed with sand and hardbottom communities, from off its southeastern shores (i.e., Vero Beach to Miami Beach), southward through the Florida Keys to the Dry Tortugas. The Keys form a boundary separating the Straits of Florida (Atlantic Ocean) from Florida Bay and the eastern Gulf of Mexico. The reef tract parallels the Keys for 356 km, from Fowey Rocks near Miami arching in a southwesterly direction before terminating west of the Dry Tortugas. The coral reef community is almost continuous except for an area between Rebecca Shoal and the Dry Tortugas. An outer reef tract lies east and south of the Keys at a distance of 4.8 to 11.3 km. Discontinuous and less biologically diverse coral reef communities continue northward along western Florida shores to the Florida Middle Grounds, a series of submerged reef pinnacles rising to within 60–80 feet of the surface about 100 miles northwest of St. Petersburg (Fig. 24). In the Vero Beach to Fowey Rock area, the stony coral cover and diversity is lower than that of the Florida Keys. Whereas 64 scleractinian species are known from the Florida Keys, the area off Boca Raton supports 25 species, the entire eastern Gulf of Mexico has 28 species, and the Florida Middle Grounds has 23 species (Jaap *et al.* 1989, Grimm and Hopkins 1977).

Florida's total coral reef and colonized hard-bottom area covers 3,035 km², of which 1,281 km² lies within the Upper, Middle, and Lower Keys (FMRI 1998), 335 km² in the Dry Tortugas (Ault *et al.* 2001), 163.7 km² off southeastern Florida (Fort Pierce to Miami), 62 km² is in the eastern Gulf of Mexico

⁴ Much of the information for the Florida section was summarized from Appendix I (Banks *et al.* 2002) of this report.

(excluding the Florida Middle Grounds), and 1,193 km² is attributed to the Florida Middle Grounds (Florida Fish and Wildlife Conservation Commission 2001, the reference for the latter three areas). Coral reefs and adjacent habitats include nearshore patch reefs, mid-channel reefs, offshore patch reefs, bank or transitional reefs, deep reefs, sand/softbottom areas, seagrass beds, and fringing mangroves. Marine communities form a mosaic of sediments, seagrasses, hard bottom, and coral reef communities. Reefs are situated on rocky elevated areas and tend to be less common in areas adjacent to channels or openings (e.g., channels through the Keys linking Florida Bay to the ocean). One of the most noticeable features of Florida Keys reefs are seaward-facing spur-and-groove formations, a constructional feature (Shinn 1963, Shinn *et al.* 1981). The spurs, formerly composed mainly of elkhorn coral (Fig. 25b) especially at depths less than 5 m, are built up from coral growth and carbonate debris trapped in the structure, while the grooves contain carbonate sands and reef rubble (Hendler *et al.* 1995). These features are typically no more than 200 m in length from offshore to onshore. In addition to bank reefs, over 6,000 patch reefs that are circular-to-oval in shape lie along the Keys reef tract in 2-9 m of water.

The only emergent coral reef ecosystem found off the continental United States is located in the Florida Keys, from south of Miami to the Dry Tortugas, most of which is under federal protection (the extreme northern end is outside the FKNMS; Biscayne National Park is managed by the NPS). Of the 5,918.1 km² area of the FKNMS that has been mapped, hardbottom, patch reef, and platform reef habitats cover an area of 1,380.8 km², while continuous and patchy seagrass habitats cover 3,468.6 km² (FMRI 1998). Recent mapping of selected areas within the Dry Tortugas delineated an additional 235 km² of coral reef habitat (Ault *et al.* 2001); benthic habitats of the rest of the Dry Tortugas have yet to be mapped. The FKNMS coral reef structure primarily consists of 2 species of fire coral, 55 species of octocoral, 64 species of scleractinian coral, and 120 species of sponge (Jaap and Hallock 1990). At deep-water sites, fine and thick turf algae, brown frondose algae, green calcareous algae, and crustose coralline algae dominate. Shallower sites are heavily encrusted with crustose coralline algae and green calcareous algae (*Halimeda* species). Surveys also indicated variability in abundance of sponges and soft corals at both deep and shallow sites, and within and outside of the fully protected zones of the FKNMS (Miller *et al.* 1999). Approximately 12,800 km² of seagrass beds lie within a 17,000-km² study area (Fourqurean *et al.* 1999). The primary species of Florida seagrasses are turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and shoal grass (*Halodule wrightii*), with at least one species of seagrass present at over 80% of all sites monitored (Fig. 26). A total of 517 species of fish (Stark 1968) have been recorded from within the FKNMS including over 260 species of reef fish (Bohnsack *et al.* 1999). Numerically, over half (59%) of all fish were from just 10 species (Fig. 27) and the majority of total fish biomass was comprised of just a few species as well (Bohnsack *et al.* 1999). Finally, 5 species of sea turtles and an estimated 23 species of marine mammals use FKNMS reef ecosystems (Fig 28)

From Vero Beach through Dade County, the reef system is characterized as three lines of discontinuous reefs that all run parallel to the shoreline and crest at 3-4 m, 6-8 m, and 15-21 m depths (Duane and Meisburger 1971, Goldberg 1973). The first and second reefs are very low profile, covered by algae and small soft corals, also known as octocorals, with an Anastasia limestone substrate and worm reef (*Phragmatopoma*). The most conspicuous organisms are the octocorals with densities that may exceed 60 individuals/m². In the past three years, outcrops of staghorn coral (Fig 25a) have been documented, especially off Broward County, where sexual spawning was observed in early August 2001 (Vargas-Ángel and Thomas in press). The third reef often has complex 3-dimensional structure, high diversity of stony or scleractinian corals and an abundance of octocorals and large barrel sponges (*Xestospongia muta*). In the Vero Beach to Fowey Rocks area, stony coral cover and diversity is lower than in the Florida Keys.

The Florida Middle Grounds is a 1,193-km² area in the eastern Gulf of Mexico, 137 km south of Appalachicola and 129 km northwest of Tarpon Springs (28°10' - 28°45'N and 84°00' - 84°25'W). The reef formations are situated in two parallel ridgelines with a north-to-northwest trend, separated by a valley. Individual banks are 12 to 15 m high, shallow crests are 21 m below sea level. The reef structures are late Pleistocene to early Holocene in age (Brooks and Doyle 1991). In winter, ocean temperature reaches 16°C and limits many tropical species from occupying these reefs. Oil 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, ten-ray star coral, and

branching fire coral (*Dichocoenia stokesii*, *Madracis decactis*, and *Millepora alcicornis*) are the most abundant stony corals on the Florida Middle Grounds. The coral cover may be as high as 30% on some reef pinnacles. The biotic characteristics (biogeographic affinity is equally temperate and tropical) are very different from the Florida Keys and the Flower Garden Banks.

Anthropogenic pressures and ecological impacts. A total of 5.09 million people reside in the four county area of South Florida, an increase of 23.5% over the past 10 years (U.S. Bureau of the Census website 2000). Of this total, 2.25 million live in Miami-Dade, 0.08 million live in Monroe (Florida Keys), 1.13 million in Palm Beach, and 1.62 million in Broward counties. But South Florida because of its climate and natural resources is a Mecca for tourism with millions of additional seasonal and temporary visitors. Miami-Dade has, on an average summer day, over 240 thousand visitors; and, on an average winter day, over 308 thousand visitors (Johns *et al.* 2001). Thus, the functional population⁵ of Miami-Dade is between 1.2-1.3 million people on an average day, depending on the season. For Broward, visitors ranged between 140-320 thousand on an average day summer and winter day, respectively. This translates into a functional population of between 1.76-1.94 million people. For Palm Beach, the estimates are between 73-183 thousand visitors and a functional population of between 1.2-1.3 million people. Finally, for Monroe, the estimates are between 30-36 thousand visitors and a functional population of between 110-116 thousand people. Overall then the functional population rises from 5.09 million people that permanently reside in South Florida to a total of between 5.56-5.92 million people once seasonal and temporary visitors are accounted for.

The environment and the economy are inextricably linked in South Florida, making the management and protection of coral reef resources critical. Many of the permanent residents and seasonal and temporary visitors use the coral reefs. In Johns *et al.* (2001), estimates were made of the market economic contributions (e.g., sales/output, income and employment) and non-market economic user values (consumer's surplus) related to both artificial and natural reef recreational reef use by both residents and visitors. In the four-county South Florida region, residents and visitors spent 18.2 million person-days fishing, diving and viewing (from glass-bottom boats) natural coral reefs, yielding an annual non-market economic use value estimate of nearly \$228 million. This annual value capitalized at a real interest rate (i.e., "interest rate net of inflation" of 3% into perpetuity) yields an estimate of the asset value of the natural reefs at \$7.6 billion.

All reef users (residents and visitors) spent 2.8 million person-days fishing, diving and viewing the natural reefs off Palm Beach County. This use resulted in \$356 million in output/sales, \$142 million in income and over 4,500 full and part-time jobs in Palm Beach County. In addition, the natural reefs off Palm Beach County had a net annual economic user value of \$42 million with an asset value of \$1.4 billion. For Broward County, reef users spent about 5.5 million person-days on the natural reefs off Broward County. This use had market economic impacts within the county of over \$1.1 billion in sales/output, \$547 million in income and generated 19,000 jobs. In addition, the natural reef use had a net annual economic user value of \$83.6 million with an asset value of \$2.8 billion. For Miami-Dade County, reef users spent almost 3 million person-days on the natural reefs with market economic impacts within the county of \$878 million in sales/output, \$419 million in income, and 13,000 jobs. In addition, the natural reef use had a net annual economic user value of \$47 million with an asset value of \$1.6 billion. For Monroe County (Florida Keys), reef users spent over 3.6 million person-days on the natural reefs in the FKNMS. This use had market economic impacts within the county of over \$360 million in sales/output, \$106 million in income, and over 7,500 jobs. In addition, the natural reefs in the FKNMS had a net annual user value of over \$55 million with an asset value of \$1.8 billion.

Another important use of coral reef habitats is fishing. In 2000, commercial fishermen received \$53.2 million for the catch landed in Monroe County. About 40-60% of the catch landed in Monroe County is related to the coral reefs. Using year 2000 data, reef-related catch was worth between \$26-32 million in revenue to the fishermen. This generated between \$35-52 million in local sales/output, between \$22-33 million in income and between 1,550-2,300 jobs (R. Leeworthy pers. comm.). The recreational fisheries on

⁵ For assessing anthropogenic pressures and ecological impacts, it is important to understand the "functional" populations of places. 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, transportation services). This number of people includes not only the permanent residents of an area, but also seasonal and temporary visitors.

natural reefs in the FKNMS (already captured in the totals for recreation above) generated \$171 million in output/sales, \$44 million in income and over 3,100 jobs. In 2000-2001, commercial and recreational fisheries dependent on the natural reefs of the FKNMS generated between \$206-223 million in output/sales, between \$66-77 million in income, and supported between 4,650-5,400 jobs in Monroe County, Florida.

These figures provide compelling evidence that adequate protection of coral reef resources is critical economically.

[REDACTED]

Throughout southeastern Florida, dredging for beach nourishment, channel deepening, and waterway maintenance have negatively impacted water quality and wildlife populations within reef habitats. Most current dredge impacts occur in the region from Dade to Martin Counties (Miami to Vero Beach). Very little dredging has occurred in the Keys since the 1980s. Chronic turbidity and deposition of silt smothers sessile invertebrates resulting in biologically barren areas. These and other regional threats must be addressed if a vibrant South Florida economy is to be sustained. Water control priorities often put near-shore reef areas at risk from millions of gallons of fresh water dumped into the nearby ocean. Stress can be imposed on reef ecosystems from reduced salinity, chemical contamination, introduced species, and high levels of nutrients from sewage, upwelling, or ground water. Ocean outfalls off South Florida introduce millions of gallons daily of secondarily treated sewage into coastal waters. One of the larger ocean outfalls located in the Florida Keys that delivered ~7 million gallons a day recently was replaced with deep-well injection (>914 m down below a containment layer) of treated effluent. The most recent threat is the installation of fiber optic cables that are deployed across the reefs. Deployment has caused abrasion and detachment of corals and sponges.

Since 1965, the number of registered private vessels has increased over six-fold in Monroe County (Ault *et al.* 1998, Fig. 29). During good weather periods in the spring and fall, boating and fishing are especially heavy in reef areas along the southeastern coastline and the Florida Keys. Fishing gear impact and signs of anchor damage in reef areas are often evident on shallow reefs.

In the past 10 years, a number of moderate to severe large-vessel grounding events (e.g., the ships *Firat*, *Pacific Mako*, *U.S. Memphis*, *Hind*, and *Sealand Atlantic*) have occurred, damaging over 0.1 km² of reef structure off the southeastern coast of Florida. In the Florida Keys, similar large ship groundings have occurred and are responsible for destroying over 0.08 km² of coral reef habitat. In addition, boat propellers have damaged more than 121.4 km² of seagrass beds and more than 600 small boat groundings were reported in 2000 alone in the FKNMS. FKNMS enforcement personnel, however, estimate that an equal or larger number of groundings go unreported there each year.

Condition of Florida's coral reef ecosystems. For South Florida's shallow-water reefs, coral bleaching events have increased in frequency and duration over the past 20 years (Jaap 1990, Hoegh-Guldberg 1999, Fig. 31). These bleaching events have resulted in significant coral mortalities, often co-occurring with massive kills of other invertebrates and fishes. In 1983, corals bleached severely on the outer reef tract of the lower Florida Keys, the same year that the massive die-off of long-spine sea urchins reached the Florida Keys. A bleaching event of greater intensity occurred in 1987 that affected the entire Florida Reef Tract. During a major bleaching event in 1990 that affected not only offshore corals but also inshore reefs, biologists determined that 65% of fire corals (*Millepora* spp.) at Looe Key reef were lost. The next major coral bleaching event occurred in 1997, never really subsided, and corals continued to bleach throughout the Keys in 1998. Bladed fire coral (*Millepora complanata*) suffered 80-90% mortality following the 1997-98 bleaching episode off the Florida Keys (W. Jaap pers. comm.), whereas remaining coral species did not suffer severe mortality. Prior to this bleaching event, fire coral used to be very abundant in the shallow spur-and-groove system throughout the Keys; since then it has remained rare or in low abundance. In the Florida Keys, coral reefs are in decline along with nearshore water quality and coral reef fishes.

Although a major problem for Florida in terrestrial and freshwater habitats, alien species are not yet considered to have invaded South Florida's near-shore marine ecosystems, although there are alien species of concern. A jellyfish (*Phyllorhiza punctata*) recently invaded the northern Gulf of Mexico and Indian River. At least 8 species of marine mollusks introduced into Florida's waters are expanding their range, including

the Indo-Pacific green mussel (*Perna viridis*). Marine crustaceans introduced to Florida waters are diverse and include six crab species, five shrimp species, three barnacle species, four isopod species, and one tanaid species; most are foreign to North American waters and were introduced by either ship hull fouling or ballast water dumping (U.S. Geological Survey Website 2001). The majority of Florida's marine fish introductions are related to the aquarium trade, with occasional reports of various exotic aquarium fish species (e.g., the Indo-Pacific lionfish, *Pterois volitans*) sighted on the Florida reef system (Courtney 1995). Another alien reef fish, the Pacific batfish (*Platax orbicularis*) was released off the Upper Keys; two of the three specimens observed were removed and delivered to the New England Aquarium (B. Keller pers. comm.).

Five fish species of fish that inhabit coral reef and mangrove habitats in the Florida Keys are considered at risk for extinction (Musick *et al.* 2000). In addition several at-risk grouper species also occur there. Florida Bay has another 6 fish species at risk for extinction. These authors contend these species are threatened because the Florida Keys has undergone extensive development over the last 30 years, much of the original habitat has been degraded or destroyed, while Florida Bay has experienced increased turbidity and altered freshwater influx.

The status and trends of coral reef and hard-bottom communities of the Florida Keys have been monitored from 1996-2000. During this period mean 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 Florida Keys (Jaap *et al.* 2001). As would be expected, gains and losses of coral cover have fluctuated among habitat types. During this same time period, 67% of 160 monitoring stations in the FKNMS had reduced stony coral species richness, 20% gained species, and 13% had an unchanged species richness (Jaap *et al.* 2001, Fig. 30). However, positive trends were noted in the 2000 survey period, when 69 out of 160 stations increased the number of species present and 35 stations remained unchanged. Significant gains and losses of several stony coral species have occurred both between years and over the entire sampling period, indicating interannual fluctuations in coral species richness at the scale of each station (44 m²); no loss of species has occurred sanctuary-wide. Macroalgae are the dominant benthic or bottom-dwelling organism at all sites, with average benthic cover generally above 75% (Miller *et al.* 1999) in the Keys and above 50% in the Dry Tortugas region (Miller *et al.* 2001). Since 1996, coral diseases on South Florida's shallow-water reefs have increased with respect to the number of stations where diseases occur, the number of coral and other species that are infected, and a slight increase in numbers of new disease phenomena observed (Dustan *et al.* 1999, Jaap *et al.* 2001). One scientist (Harvell 2000) is directly linking the increase in water temperatures with the increase in coral diseases. In 1986, large outbreaks of black-band disease began appearing on coral reefs throughout the Florida Key. Over the past 5 years, there have been significant increases in white-complex disease and other coral diseases. Populations of algae and attached invertebrates (e.g., sponges, soft corals) fluctuated widely in the last few years at survey sites in the Florida Keys, due to several large-scale storms that affected the local area. Hurricanes Georges and Floyd in 1998 and Hurricane Irene in 1999 had visible effects on populations of attached bottom animals and algae in most areas of the Keys (Aronson *et al.* 2001). At this time, 13 of 16 groupers, 7 of 13 snappers, 2 of 5 grunts, and 1 wrasse are over-fished and below their 30% spawning potential ratio, based on Federal standards (Ault *et al.* 1998, Fig.). Non-sustainable fisheries practices are likely restructuring trophic interactions in reef environments, leading to secondary effects such as reduced reproductive capacity (PDT 1990) and shifts in ecosystem structure and function. Most significant of these observations is that relatively few individual fish of legal, harvestable size were seen. In June 1980, a large fish kill occurred throughout the Florida Keys. Hundreds of thousands of reef fish died within a very short time frame. The fish appeared to have had a disease outbreak that resembles *Brooklynella*, a disease that has occurred in more recent years (1997, 1998, and 2000) in the Florida Keys.

In 1987, seagrasses began to die in the upper basins of Florida Bay, with consequences for downstream reef ecosystems (Zieman *et al.* 1999). This die-off, resulting ultimately in the loss of an estimated 200 km² of seagrass, was probably due to a multiple of environmental stressors including a marine slime mold. Dead seagrass decomposed, released nutrients, and stimulated a plankton bloom of blue-green algae (Cyanobacteria). Toxins from the bloom caused sponges and fish to die. Because Florida Bay and near-shore waters provide critical nursery and juvenile habitat for a variety of reef species, declines seen in these areas indirectly affect the overall health and structure of coral reefs.

Based on the condition of coral and fish populations, reef communities on the southeastern coast of Florida are in relatively good condition. The Florida Current (Gulf Stream) moderates winter temperatures and occasionally brings algal blooms onto the reefs. During cold-water upwelling events, however, fish kills are common. Reef tracts off Boca Raton and Sunny Isles, however, have been degraded from the physical impact of managed dredge operations. Since 1989, algal blooms of an invasive green alga dead-man's fingers (*Codium isthmocladium*) to the north and a cyanobacterium (*Micetocolus lynbyaceus*) to the south were common on reefs off Southeast Florida. Algal blooms reached massive proportions on some reefs off Palm Beach County. While these blooms continue, they have abated somewhat since 1992. It is unclear what the nutrient source for the blooms may be but nutrient-rich water from upwelling, eutrophication from sources such as sewage pollution, and intrusion of nutrient-rich ground water are under investigation (R. Dodge pers. comm.).

Recent scuba and submersible expeditions (i.e., Sustainable Seas Expeditions 2000 and 2001) to the Florida Middle Grounds examined a number of reef structures and found them apparently healthy (Jaap pers. obs.). The isolation and distance of this area from populated shorelines provide protection from pollutants and from heavy recreational fishing activity.

Resource management and MPAs. The Florida Keys National Marine Sanctuary (FKNMS) is a large marine protected area (MPA) that encompasses 9,850 km² of coastal waters and 1,381 km² of coral reef. The sanctuary was established in 1990 to protect the coral reef resources of the Florida Keys and to provide for the sustainable use of the resources. The sanctuary is managed by the National Oceanic and Atmospheric Administration (NOAA) and the Florida Department of Natural Resources (FDNR). The sanctuary is a unique and valuable resource that provides a wide range of ecosystem services, including carbon sequestration, habitat for marine life, and protection from storms and hurricanes. The sanctuary is also a popular destination for tourists and researchers alike.

In 1990, most of the coral reef tract of the Keys was afforded Federal protection with the designation of the FKNMS. Now 9,850 km² of coastal waters as well as 1,381 km² of coral reef are under NOAA management. Oil and hydrocarbon exploration, mining, and large shipping traffic are excluded from the FKNMS. Anchoring on corals in shallow water is prohibited, as is touching coral, collecting living or dead coral, and taking "live rock," a product of the aquarium trade. The FKNMS has authority to address discharges within its boundary as well potential pollutants that originate from outside, offering protection for water quality that is critical for coral reef health and vitality. Implemented in July 2001, the Tortugas Ecological Reserve is a 518-km² fully protected ecological reserve that conserves significant deep-water reef resources and fish communities unique to the Tortugas region of the Florida Keys. With the other fully protected zones in the Sanctuary, the Tortugas Ecological Reserve increases the total protected area of coral reefs within the FKNMS to 10%. An adjacent 158-km² fully protected Research Natural Area inside the Dry Tortugas National Park has been proposed to conserve critical shallow water resources. Along with the 23 no-take zones in the FKNMS, the new fully protected reserves account for approximately 7.4% of Florida's coral reef habitat.

In 1997, the FKNMS established a network of 23 fully protected zones that protect 65% of its shallow coral reef habitats. Lobstering, fishing, spearfishing, shell collecting, and consumptive activities are prohibited in these areas. For example, the 30.8-km² Western Sambo Ecological Reserve protects offshore reefs as well as all other habitats, including mangrove fringe, seagrasses, productive hard-bottom communities, and patch reefs. Results after three years of FKNMS monitoring show significant improvement in populations protected by no-take provisions. Despite drastic population declines elsewhere, numbers of some fish species in the fully protected zones of the Sanctuary are increasing to some degree. Analyses of three years of reef fish abundance data show that mean densities (number of individuals per sample area) for the exploited fish species gray snapper (*Lutjanus griseus*), yellowtail snapper (*Ocyurus chrysurus*), and grouper (several economically important species were combined) are higher in the Sanctuary Preservation Areas (SPAs) than in fished reference sites (Bohnsack *et al.* 2001). Complementing this data is an overall increasing trend in average estimated abundances of gray snapper, schoolmaster (*L. apodus*), and yellowtail snapper after the establishment of the fully protected zones in 1997 at 16 sites monitored by Reef Environmental Education Foundation (R.E.E.F.) volunteers (Pattengill-Semmens 2001, Fig. 32). Legal-size spiny lobsters (*Panulirus argus*) continue to be more abundant and their average size larger in SPAs than in reference sites of comparable habitat (Cox *et al.* 2001). Also, catch rates (number of lobsters per trap) are higher within the Western Sambo Ecological Reserve than within two adjacent fished areas at all times of the

year (Gregory 2001). Historically overfished queen conch populations, however, have remained low in the last decade, despite cessation of harvesting of this species by commercial and recreational fishermen in the mid-1980s (Fig. 33b). An intensive monitoring program for queen conch continues to find no significant differences in conch aggregation sizes, density, or abundance between fully protected zones and reference sites (Glazer 2001). Attempts to supplement wild populations with laboratory-reared stock, and experiments to improve the reproductive output of this species are designed to ameliorate the long-term demise of queen conch populations in the Keys.

Fishery management plans written by State and Federal Fisheries Management Councils govern commercial fishing (one of the largest industries in the Florida Keys region) throughout the region and regulate heavily with measures that include annual catch quotas, closed seasons, gear restrictions, and guidelines that set minimum catch sizes. These regulations have been developed for most commercially important invertebrates and finfish. The State collects landing information on approximately 400 kinds of fish, invertebrates and plants to track trends in catch and evaluate regulations (U.S. Department of Commerce 1996). The Florida Middle Grounds is designated a State Habitat Area of Particular Concern with special rules that limit fishing gear.

Mapping and monitoring capacity. Several mapping efforts were undertaken in the FKNMS in the 1990s. Florida Fish and Wildlife Conservation Commission's Florida Marine Research Institute (FMRI) and NOAA published digital benthic habitat maps for the Florida Keys in 1998 (FMRI/NOAA 1998). The digital maps depict 30 different types of benthic habitats found throughout the Keys. Recently, the Dry Tortugas region was characterized (Schmidt *et al.* 1999). This and other mapping efforts have produced a wealth of information unique to the Dry Tortugas region of the Florida Keys. There is a very remarkable baseline map of Tortugas benthic habitats from 1882 (Agassiz 1882). The map and report suggest a 0.4-km² loss of elkhorn coral in a 100-year period. Using side-scan sonar, multi beam, and Lidar, Continental Shelf Associates, University of South Florida School of Marine Science, and NOVA Southeastern University mapped portions of the Florida Middle Grounds, Pulley Ridge, and Dade, Broward, and Palm Beach counties. ~~Figure 34. Aerial view of the coral reef habitat surrounding the Dry Tortugas.~~

Since 1994, comprehensive long-term monitoring of coral reef condition is conducted in the FKNMS through the Water Quality Protection Program funded by USEPA, and, more recently, by NOAA. This program monitors water quality, corals/hard-bottom communities, and seagrasses, and the resulting data allow scientifically credible comparisons of benthic cover, diversity, and abundance with reasonable error estimates among the diverse habitats that comprise this complex ecosystem. At 43 permanently marked sites, biodiversity, coral condition, and cover are recorded annually (Jaap *et al.* 2001). Reef fish diversity surveys, conducted since 1979, document reef fish species composition, abundance, frequency, and size estimates (Bohnsack *et al.* 1999). The status of spiny lobster, queen conch, and benthic cover are also monitored sanctuary-wide. Thirty seagrass station locations are visited concurrent with water quality monitoring to detect relationships between seagrass health and water quality. Water quality parameters, measured at 154 fixed stations, include salinity, temperature, dissolved oxygen, turbidity, relative fluorescence, and light attenuation. Water chemistry variables measured at each station include concentrations of nitrate, nitrite, ammonium, dissolved inorganic nitrogen, and soluble reactive phosphate. Concentrations of total organic nitrogen and carbon, total phosphorus, and silicate are also measured, along with the biological components chlorophyll *a* and alkaline phosphatase activity (Jones and Boyer 2001). Continuous monitoring of selected physical parameters of seawater and meteorology are recorded by instrumentation that is installed along the Florida Keys reef tract, as part of the SEAKEYS program. Also, *in situ* thermographs record water temperature every two hours at inshore and offshore stations in the FKNMS.

The effects of no-take management of the 24 discrete marine reserves in the FKNMS are being assessed through the Zone Monitoring Program. Measures of effectiveness being monitored include the abundance and size of fish, invertebrates, and algae. Surveys of the economic and aesthetic values of users (including compliance with regulations) are also being conducted. Changes in ecosystem structure (size and number of invertebrates, fish, corals, and other organisms) and function (such as coral recruitment, herbivory, predation), and human uses of zoned areas are also monitored (Fig. 34). Scientists from the National Undersea Research Center at the University of North Carolina at Wilmington have conducted rapid, large-

scale sampling of benthic communities in the FKNMS since 1998 as part of the Zone Monitoring Program. Mobile invertebrates such as spiny lobster and queen conch are being monitored by the FMRI both inside and outside the FKNMS zones. Populations of spiny lobster are also being tracked in the Dry Tortugas, where National Park designation eliminated harvesting and subsequently allowed individuals there to grow to larger sizes than elsewhere.

In contrast to the monitoring underway in the FKNMS, information on the condition of southeastern Florida reefs is being compiled from results of disparate studies on environmental impacts to specific sites (e.g., dredge insults, ship groundings, pipeline and cable deployments, beach renourishment). Typically, these studies were conducted for a few years duration and provided baseline data for only a few sites. Academic studies were also limited to a few locations and short-time frames. Although presently there is no formal monitoring at the Florida Middle Grounds, a minimum of four long-term monitoring sites should be initiated (Jaap pers. comm.). At least some of the sites selected for monitoring should be the same as those from the Hopkins *et al.* (1977) study to see how conditions have changed over time and should involve comparable methods and video transects.

Puerto Rico⁶

Reef characterization. The Commonwealth of Puerto Rico, with a combined land area of about 8,897 km² (roughly the size of Rhode Island) and a linear coastline of 620 km, are the easternmost islands of the Greater Antilles, located between La Hispaniola and the Virgin Islands. Commonwealth islands lie on a submarine platform and include Puerto Rico, Vieques, Culebra, Culebrita, Desecheo, Mona, and Monito. With the exception of Monito Island, NOAA recently mapped Puerto Rico's coral reef ecosystem and associated habitats (e.g., sand, hard-bottom, algae, mangroves) to a depth of about 20 m and delineated a total coral reef ecosystem area of 5,077.6 km². Coral reef and colonized hardbottom habitat comprised a total of 709.8 km² (14.0%)—566.8 km² (13.2%) off the main island of Puerto Rico, 67.6 km² (15.3%) off Vieques, 50.8 km² (21.5%) off Culebra, 4.2 km² (30.0%) off Desecheo, and 20.3 km² (24.8%) off Mona. Total seagrass habitat comprised 589.4 km² (11.6%), a mangrove fringe of 72.4 km² (1.4%) while macroalgal-dominated areas covered 95.2 km² (1.9%). Overall, 93 coral taxa, including 43 scleractinian corals, 42 octocorals, 4 antipatharians, and 4 hydrocorals have been reported from Puerto Rico (A. Bruckner pers. comm.). According to FishBase (2002), out of the 568 marine species recorded for Puerto Rico, 242 species are considered reef-associated.

Puerto Rico, the main island, has coral growth along much of the insular shelf, but reef development is restricted to eastern, southern, and western coasts as a result of physical, climatic, and ocean conditions. Three major types of reefs have been identified: 1) submerged hard-substrate rock reefs on the northwestern and western coast with moderate to high topographic relief, a high cover of turf algae, and patchy coral growth; 2) flat eolianite (a rock formed on land by cementation of calcareous dune sands) reefs, found mostly along the northern coast, with a high cover of turf algae, sponges, and isolated encrusting corals; and 3) fringing, patch, bank, and shelf-edge coral reefs found off the main island and surrounding many of the small islands and cays. The reefs with the highest living coral cover (>30%) included outer reefs and shelf-edge reefs off La Parguera, Tourmaline Reef, south of Mayaguez, Algodones Reef near Naguabo and La Cordillera off the eastern coast near Fajardo; these reefs are upstream of large riverine discharges and are the farthest from shore (García *et al.* 1999). In contrast, dead coral reefs were identified near Mayaguez, Guayanilla, and Ponce, and included near-shore areas affected by dredging, sewage, industrial discharge, ship traffic, and river discharge. The southwestern coast is characterized by a broad carbonate platform that extends up to 15 km offshore and supports an extensive system of near-shore fringing and offshore shelf-edge coral reefs with varying degrees of wave exposure and sediment characteristics (Morelock *et al.* 2001). Mangroves fringe the coastline, with extensive seagrass beds in shallow water around near-shore and inner reefs. There is no river discharge but local sewage is discharged into a mangrove channel; clear-cutting of the hillsides surrounding La Parguera has contributed to increased sediment runoff during rainy periods, and reefs may be affected by sewage discharge from upstream sources (e.g., off Guayanilla, Guanica, and Ponce).

⁶ Information for the Puerto Rico section was summarized from Appendix II (Matos *et al.* 2002) of this report and from Bruckner (pers. comm.).