

The State of Coral Reef Ecosystems of the Flower Garden Banks, Stetson Bank, and Other Banks in the Northwestern Gulf of Mexico

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INTRODUCTION AND SETTING

The East and West Flower Garden Banks (EFGB and WFGB) were designated as the Flower Garden Banks National Marine Sanctuary (FGBNMS) through the National Oceanic and Atmospheric Administration (NOAA) in January 1992. The two banks are prominent geological features located near the outer edge of the continental shelf in the northwestern Gulf of Mexico, approximately 192 km southeast of Galveston, Texas (Figure 8.1). These features, created by the uplift of underlying salt domes of Jurassic origin, rise from surrounding water depths of over 100 m to within 17 m of the surface. The northernmost thriving coral reef communities in North America cap the shallow portions of the EFGB and WFGB. They are relatively isolated from other coral reefs of the Caribbean and Gulf of Mexico, located over 690 km from the nearest reefs of the Campeche Bank off Mexico's Yucatan Peninsula, and over 1,200 km from the coral reefs of the Florida Keys. The area of the EFGB (27 54.5' N, 93 36.0' W) comprises about 65.8 km² of which about 1.02 km² is coral reef. Located 19.3 km to the west, the WFGB (27 52.5' N, 93 49.0' W) comprises about 77.2 km² of which about 0.4 km² is coral reef (Gardner et al., 1998).

Structurally, the coral reefs of the Flower Garden Banks are comprised of aggregations of large, closely spaced boulder and brain coral heads that grow to up to 3 m or more in diameter and height (Figure 8.2). Reef topography is relatively rough, with many vertical and inclined surfaces. Between groups of coral heads, there are numerous sand patches and channels. Coral growth is relatively uniform over the entire top of both banks, occupying the bank crests down to about 50 m. As the reef slopes on the flanks of the coral caps, the corals grow flatter and individual heads can cover large areas. Despite the low species numbers on the reef crest, the reefs exhibit extremely high coral cover, ranging on average between 45-52% down to 30 m depth, and 70% in areas down to at least 43 m depth.

Probably due to its geographic isolation, water temperature, and other factors, there is a relatively low diversity (only about 21 species) of reef-building corals on the Flower Garden Banks. Interestingly, the coral reefs of the Flower Garden Banks contain no elkhorn or staghorn corals, and no shallow-water sea whips or sea fans (gorgonians) that are common elsewhere in the Caribbean. Deepwater surveys below 43 m, however, reveal a rich diversity of gorgonians and antipatharian corals.

Stetson Bank was added to the FGBNMS in 1996. It is located 48 km to the northwest of the WFGB and is also associated with an underlying salt dome. Stetson Bank is classified as a mid-shelf bank (Rezak et al., 1985), and is comprised of claystone/siltstone outcrops forming distinct pinnacles near its northern edge. Stetson Bank is not a true coral reef, but it does contain a low diversity coral community in addition to a prominent sponge fauna. Stetson Bank is dominated by fire coral (*Millepora alcicornis*) and in certain areas, ten-ray star coral (*Madracis decactis*). These two species comprise about 32% coral cover in the pinnacle region. Stetson Bank is composed of claystone outcroppings that have been pushed up to within 17 m of the sea surface. Including the two dominant species, about 10 species of coral have been documented. The pinnacle region is the most conspicuous feature of the bank, which stretches along the northwest face of Stetson Bank for approximately 500 m. With the addition of Stetson Bank, the FGBNMS encompasses 145.8 km² and includes the entire bank areas of each of the three features, including the shallow coral reef areas.

The user groups of the FGBNMS are recreational SCUBA divers and recreational and commercial fishers. Three dive charter vessels routinely visit the Sanctuary. Limited data are available to sufficiently quantify the numbers of private vessels and fishing vessels visiting the FGBNMS.

In addition to the coral reefs within the FGBNMS, there are a number of other reefs and banks in the northwestern Gulf of Mexico that contain corals or coral communities. The Flower Garden Banks and Stetson Bank are but

¹ Flower Garden Banks National Marine Sanctuary

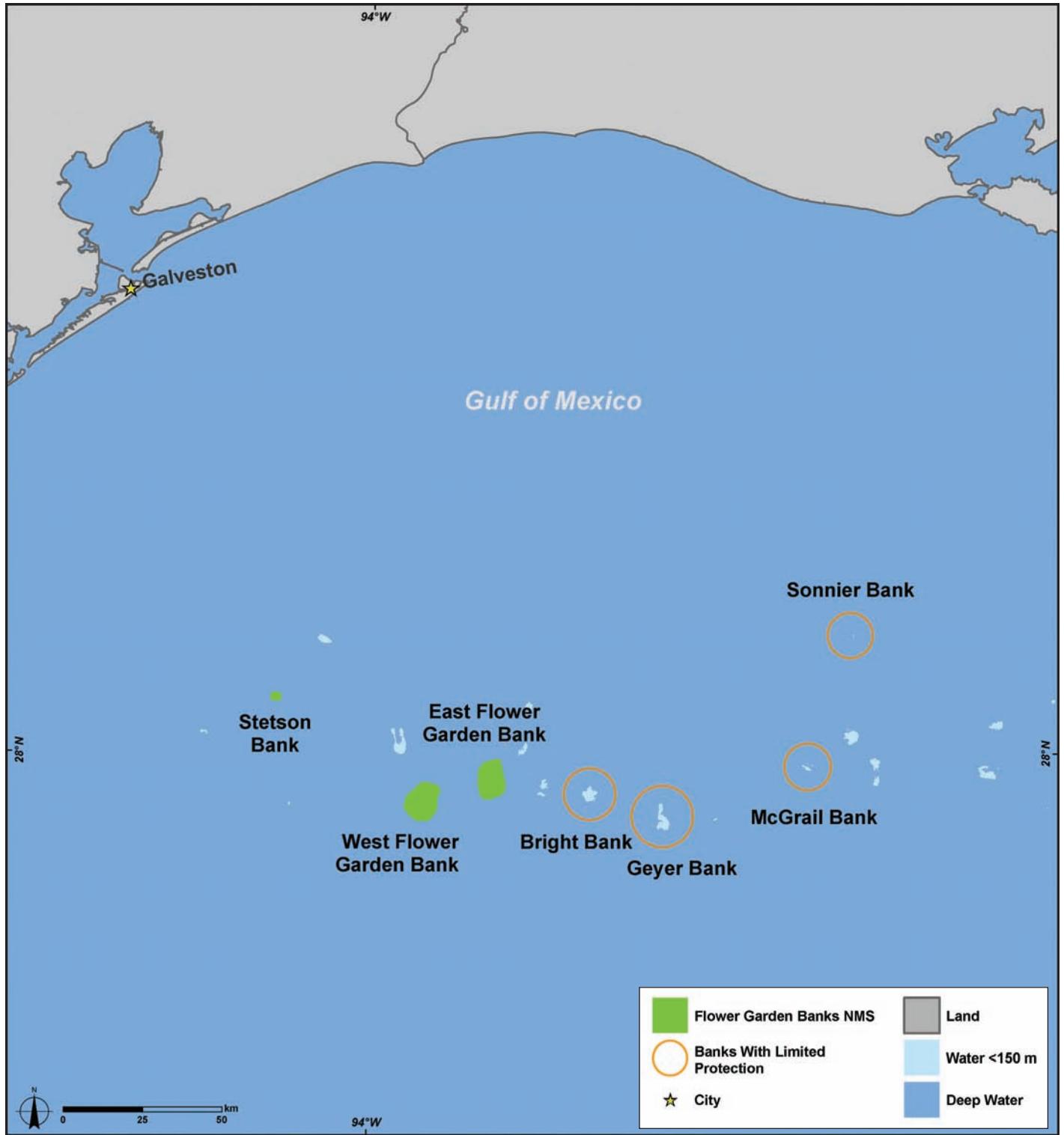


Figure 8.1. Map showing the locations of the coral banks of the Gulf of Mexico. While some of the banks are protected by the provisions of the FGBNMS, unprotected coral communities are present at Bright, Sonnier, Geyer, and McGrail Banks. These banks are part of the network of reefs and banks which are biologically and ecologically associated with the ecosystems of the FGBNMS. Map: A. Shapiro. Source: D. Weaver.

three of a network of over one hundred continental shelf-edge features off the coasts of Texas and Louisiana. Many of these topographic features were the subjects of baseline scientific investigations in the late 1970s and early 1980s (Rezak et al., 1985). These studies first documented that a number of the banks contained coral reef resources. Recent surveys by FGBNMS staff and collaborators have further characterized several of these features. At least four of these reefs and banks harbor important populations of scleractinian coral: Bright Bank (11 species; Rezak et al., 1985; FGBNMS observations), Sonnier Bank (nine species; Rezak et al., 1985; Weaver et al., in press), Geyer Bank (four species; Rezak et al., 1985, FGBNMS observations), and McGrail Bank (nine species; Rezak et al., 1985; Weaver et al., in press; FGBNMS observations). The coral communities at McGrail Bank are especially significant. Recent surveys have revealed a community dominated by the blushing star coral (*Stephanocoenia intersepta*) which covers up to 30% (Schmahl and Hickerson, in press) of the seafloor in some areas at depths between 45 m and 60 m (Figure 8.3).

In addition, many of the other banks in the northwestern Gulf of Mexico contain significant communities of a variety of deeper water coral assemblages, characterized by antipatharians, gorgonians, solitary corals, and species of branching corals such as *Oculina* spp. and *Madrepora* spp. These types of communities are typically observed in depths from 60 m to 150 m. All of the reefs and banks in this vicinity provide hard bottom substrate that has been colonized by a high diversity of benthic invertebrates, and provide important habitat to a wide range of reef fish species (Dennis and Bright, 1988). These banks are currently unprotected, with the exception of regulation of direct impacts from oil and gas development. Further investigations are warranted to fully determine the extent of these coral resources.



Figure 8.2. Large boulder corals are a striking feature of the FGBNMS landscape. The coral caps of the FGBNMS boast over 50% coral cover. Photo: Joyce and Frank Burek.

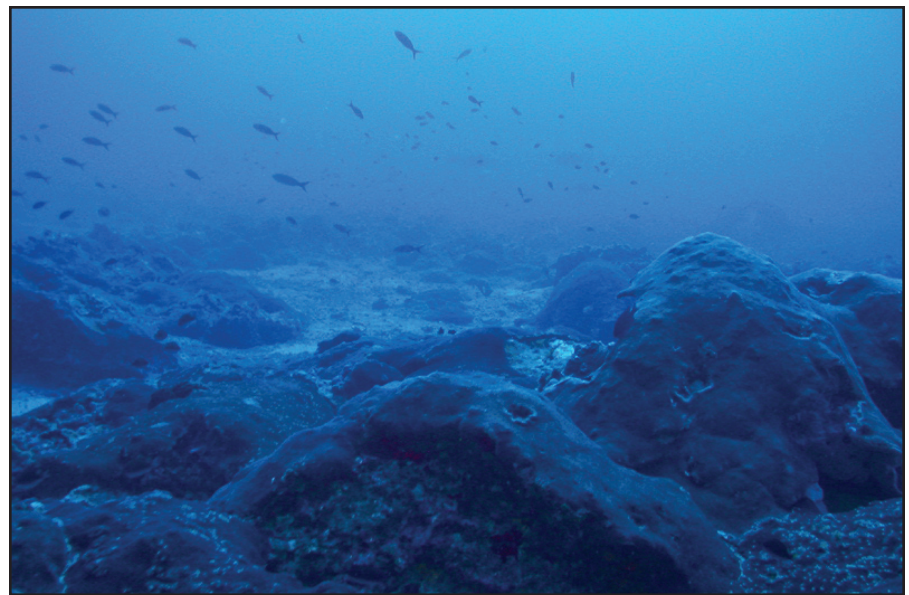


Figure 8.3. McGrail Bank *Stephanocoenia* community at approximately 42 m depth. Estimates of percent coral cover reach upwards of 30%. Photo: FGBNMS and National Undersea Research Center-University of North Carolina, Wilmington.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

The location and depth of these coral reefs buffer them somewhat from the short-term effects of global warming and climate change. However, even though the effects of coral bleaching are relatively low to date (less than 4% annually; Hagman and Gittings, 1992; Gittings et al., 1993; US DOI-MMS, 1996; Dokken et al., 1999, 2003; Precht et al., in press), some bleaching is routinely observed, mostly when the water temperature approaches 30°C. Data on bleaching incidence from 1989-2003 is given in Figure 8.4. Overall, bleaching has resulted in negligible mortality (Hagman and Gittings, 1992). However, bleaching events and their severity are predicted to increase as global ocean temperatures increase.

Diseases

The incidence of disease is very low at the EFGB and WFGB of the FGBNMS. Observations of white plague type II were noted in *Montastraea annularis*, *M. cavernosa*, *Colpophyllia natans*, and *Diploria strigosa* during the 2002-2003 monitoring effort (Precht et al., in press) outside the random transect surveys. No white band disease is present.

Considering the magnitude of the threat from coral diseases, we feel it is important to increase awareness among scuba divers to thoroughly wash scuba equipment, particularly wetsuits, before traveling to a new diving destination. There is no indication that disease can be transmitted through unclean gear, but proactive behavior may lessen the risk of disease transmission.

Tropical Storms

Since 1979, three hurricanes have passed near the Flower Garden Banks (Figure 8.5). At the EFGB and WFGB, it is suspected that coral boulders would be susceptible to toppling, particularly *Diploria strigosa* heads that are subjected to bioerosion, a process that produces mushroom-shaped colonies - large heads of coral on spindly coral stalks (Figure 8.6)

Anecdotal reports from scuba divers noted up to 1.5 m sand waves in the sand flats of the Banks after tropical storms. At Stetson Bank, scouring of

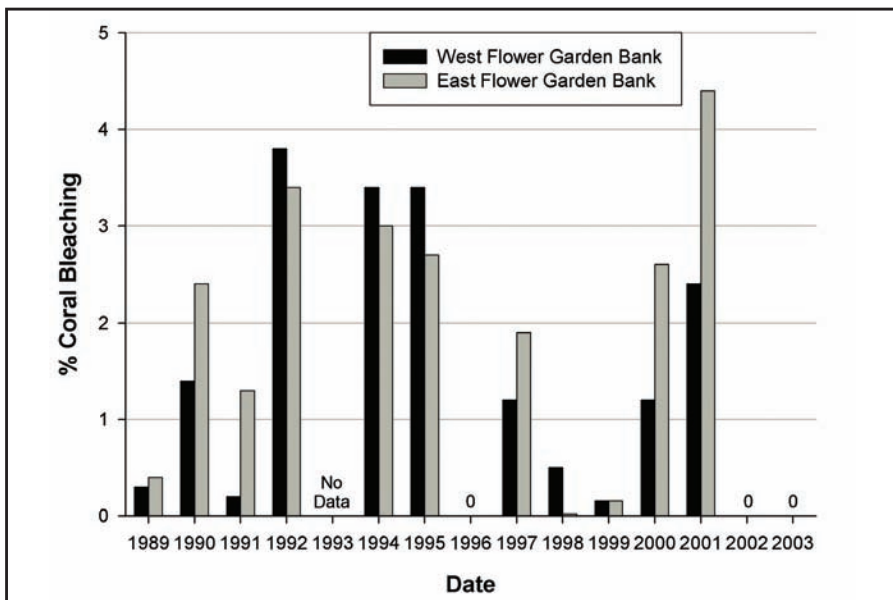


Figure 8.4. Incidence of bleaching at the East and West Banks of the FGBNMS from 1989-2003. Source: USDOI-MMS, 1996; Dokken et al., 1999, 2003; Precht et al., in press.

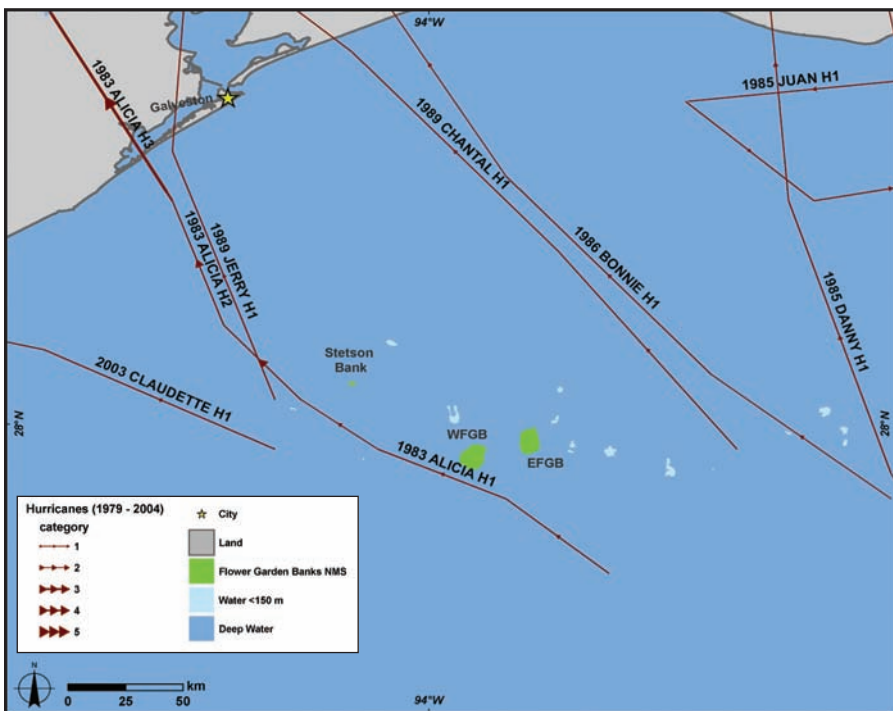


Figure 8.5. A map showing the paths and intensities of tropical storms passing near the FGBNMS and nearby banks, 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

the claystone/siltstone valleys occurs, as well as toppling of the claystone pinnacles.

Coastal Development and Runoff

Primary sources of potential degradation of water quality include coastal runoff, river discharges, and effluent discharges from offshore activities such as oil and gas development and marine transportation (Deslarzes, 1998). Oxygen-depleted (hypoxic) near-bottom waters have been found in a large area of the northern Gulf. Although relatively far from the Flower Garden Banks, there is concern that this area could grow and impact the outer continental shelf. Often called the 'dead zone' this area has included up to 16,500 km² on the continental shelf from the Mississippi delta to the Texas coast.



Figure 8.6. These colonies of *Diploria strigosa*, mushroom-shaped due to bioerosion at their base, may be more susceptible to toppling during storms. Photo: Joyce and Frank Burek.

General coastal runoff and degraded nearshore water quality can potentially impact the banks through cross-shelf transport processes which bring turbid, nutrient-rich water offshore. Deslarzes (in press) postulates the fluorescent bands observed in the carbonate skeletons of some corals come from the seasonal transport of nearshore water onto the FGBNMS, which may be tainted by urban, agricultural, and biological contaminants.

Research using nitrogen isotopes suggests a pathway for direct primary nitrogen input from coastal river sources from a considerable distance. While nitrogen isotopes from the Flower Garden Banks have signatures of ocean origin (K. Dunton, pers. comm.), benthic algae from Stetson Bank have a distinct nitrogen isotope signature similar to plants found in coastal estuarine systems. These findings suggest that coastal influences are reaching only as far as Stetson Bank.

Coastal Pollution

Coastal pollution is not a major concern at this offshore location.

Tourism and Recreation

Recreational scuba diving is popular and the demand appears to be increasing. There are currently three live-aboard charter dive vessels that regularly visit the banks (Figure 8.7). Each of these vessels can carry up to 35 divers. In 1997, a survey of charter dive operations revealed that an estimated 2,350 divers visited the Flower Garden Banks. These divers spent \$870,000 in Texas, of which approximately \$636,000 was spent in



Figure 8.7. Recreational dive charter vessel on mooring at FGBNMS. Photo: Russ Wilkins.

the local economy of Freeport, where it generated \$1.1 million in sales/output, \$477,000 in income, and 24 full-time and part-time jobs. An additional \$234,000 was spent in other areas of Texas, with \$559,000 in sales/output, \$228,000 in income, and 11 jobs (Ditton and Thailing, 2001). While scuba diving has helped these economies, resource managers suspect that recreational dive vessels often discharge inadequately treated sewage effluent into Sanctuary waters.

Fishing

The impacts of fishing and associated fishing activities are not well known. At this time, only traditional hook and line fishing is allowed in the Sanctuary. However, illegal fishing by both commercial long-liners and recreational spearfishers has been reported. Targeted fishing efforts, which are allowed under current regulations, could have a significant detrimental impact on snapper and grouper populations.

Lost and discarded fishing gear has been observed in the FGBNMS. Such objects can cause localized physical injury to coral reefs and have been known to entangle and injure loggerhead sea turtles and other organisms. Fishing bycatch has occasionally been reported by scuba divers, and shrimping bycatch is illegally discarded on Stetson Bank. Stetson Bank is closer to shore, and is often targeted by recreational fishers (Figure 8.8). It is suspected that Stetson Bank is more prone to mechanical injury by fishing due to the relatively soft nature of the claystone/siltstone substrate. Continuous weakening of the substrate by fishing gear could possibly render it more susceptible to tropical storm and hurricane events.

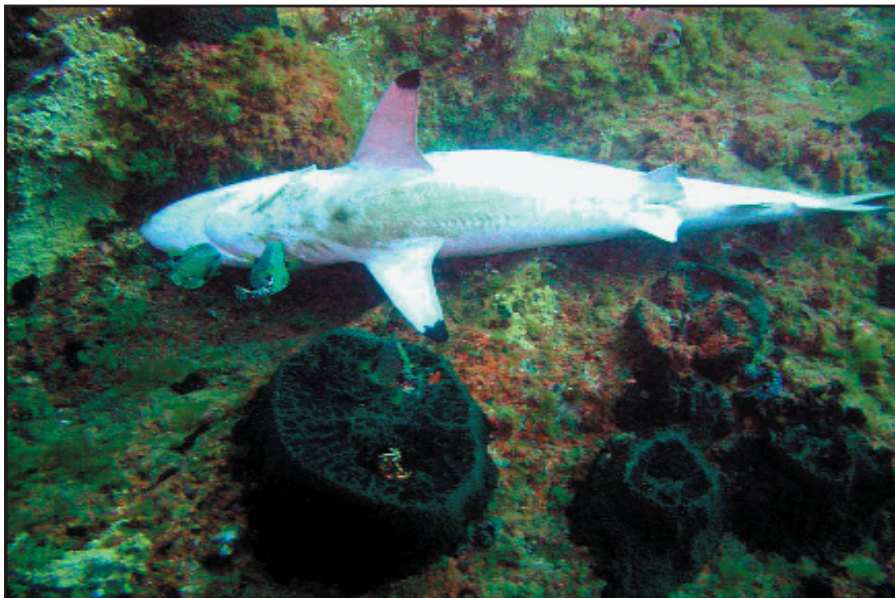


Figure 8.8. Dead spinner shark (*Carcharhinus brevipinna*) on Stetson Bank in April 2004. While it is not known what caused the death of this animal, it is suspected that the death resulted from fishing activity. Photo: C. Loustalot.

Trade in Coral and Live Reef Species

This activity is prohibited by Sanctuary regulations.

Ships, Boats, and Groundings

Groundings do not occur at the FGBNMS due to the depth of the coral caps. However, anchors from large ships can have devastating local impacts to the living coral reef. Over the last 20 years there have been a number of incidences of significant impacts caused by the anchoring of large industry vessels, freighters, and fishing vessels (Gittings et al., 1992). Foreign-flagged cargo vessels have occasionally anchored at the Flower Garden Banks without knowing of the anchoring restrictions. There have been at least three large vessel anchoring incidents since 1994. In 2002, the FGBNMS became the first international 'no-anchor zone' through the development of new language integrated by the International Maritime Organization.

Marine Debris

Lost and discarded fishing gear, including long-lines, floats, and nets have been observed at the Flower Garden Banks and Stetson Bank (Figure 8.9). Such incidents cause localized physical injury to coral reef resources, and have been known to entangle and injure resident and transient sea turtles and other organisms. Debris originating from historic activities, including seismic cables from acoustic surveying efforts, remain embedded in the coral reef around the flanks of the EFGB and WFGB. Remnants of anchors and old engine blocks are scattered throughout the three sites.

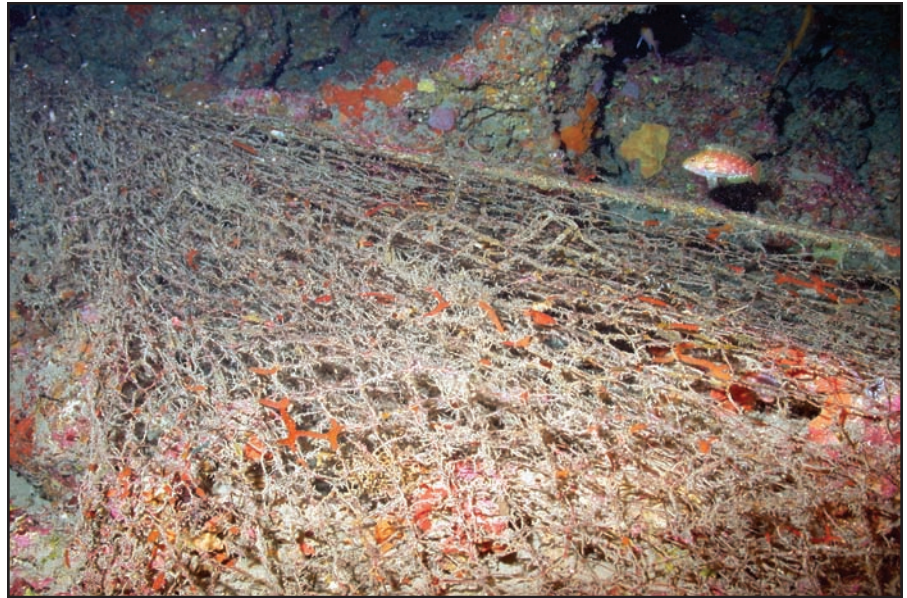


Figure 8.9. A discarded net on WFGB. Photo: FGBNMS and National Undersea Research Center-University of North Carolina, Wilmington.

Aquatic Invasive Species

In August 2002, an invasive coral species, *Tubastraea coccinea*, was photographed at the EFGB on reef substrate at around 24 m depth (Figure 8.10). Prior to this report, no evidence of the coral had been reported on natural reef substrate in the Gulf of Mexico. However, it was known to inhabit the underwater structures of seven oil and gas platforms off the Texas coast. The first known sighting of *T. coccinea* on platforms in the Gulf occurred in 1991, and it was later documented on several other platforms in the Gulf of Mexico (Fenner, 2001; Fenner and Banks, 2004). This coral species currently thrives on High Island A389A (HIA389A), a gas platform located within the EFGB boundaries.



Figure 8.10. *Tubastraea coccinea*, an invasive coral species, was found on the underwater structure of gas platform HIA389A, which is located within the boundaries of the FGBNMS. This species threatens natural reef habitats both within and outside Sanctuary boundaries. Photo: Joyce and Frank Burek.

In September 2004, several dozen colonies of *T. coccinea* were also documented by the FGBNMS research team at Geyer Bank, located 52 km east-southeast of the EFGB. This is further evidence of the threat to natural reef ecosystems by this invasive species.

Security Training Activities

No security training activities occur in the FGBNMS.

Offshore Oil and Gas Exploration

The northern Gulf of Mexico is one of the most active areas for oil and gas exploration and development in the world. By the end of 2003, approximately 6,500 production platforms had been installed (of which approximately 2,400 were removed), about 43,300 wells had been drilled, and 168,474 km of pipeline installed (Figure 8.11).

The Gulf of Mexico accounts for more than 91% of the oil and 97% of the natural gas produced in offshore U.S. waters (J. Sinclair, pers. comm.).

Within the four-mile zone of both the EFGB and WFGB regulated by the U.S. Department of the Interior-Minerals Management Service (MMS), there are currently 14 production platforms (six at the West Bank and eight at the East Bank, including one subsea station) and approximately 178.24 km of pipeline, half of which are dedicated oil pipelines (Deslarzes, 1998). Over the past two years, three platforms and approximately 134 km of pipeline have been added within the MMS four-mile regulatory zones of the East and West Banks. One platform and approximately 17.44 km of pipeline is located within 6.5 km of Stetson Bank.

There is one gas production platform (HIA389A) located within the EFGB boundary, less than 2 km from the coral cap (Figure 8.12). Recent exploration activities have been conducted by this platform. A pipeline has been constructed through the Sanctuary to tie in HIA389A to a subsea station outside of the Sanctuary boundaries. This pipeline will be used to bring in product from the subsea station to HIA389A for processing and shipment to shore.

Potential impacts from offshore oil and gas exploration and development include accidental spills, contamination by drilling, related effluents and discharge, anchoring of vessels involved in placing pipelines, drilling rigs and production platforms, seismic exploration, use of dispersants in oil spill mitigation, and platform removal. In spite of the intense industrial activity, long-term monitoring studies indicate no significant detrimental impact to the coral reefs of the FGBNMS from nearby oil and gas development (Gittings, 1998). Fortunately, there have been no major oil spills or impacts from these activities.

While the structures of the platform appear to provide artificial substrate for both motile and sessile marine populations, there is growing concern that the oil and gas structures may act as vectors for the spread of invasive and exotic species. An example is the introduction and establishment of sergeant majors (*Abudefduf saxatilis*) at the FGBNMS and recent (1997) appearance of yellowtail snapper (*Ocyurus chrysurus*). Pattengill (1998) suggests that these resulted from "hopping" along the platforms in the eastern side of the Gulf, where they have been reported by recreational fishers. We suspect that this is the vector used by the orange cup coral, *T. coccinea*, to reach the EFGB.

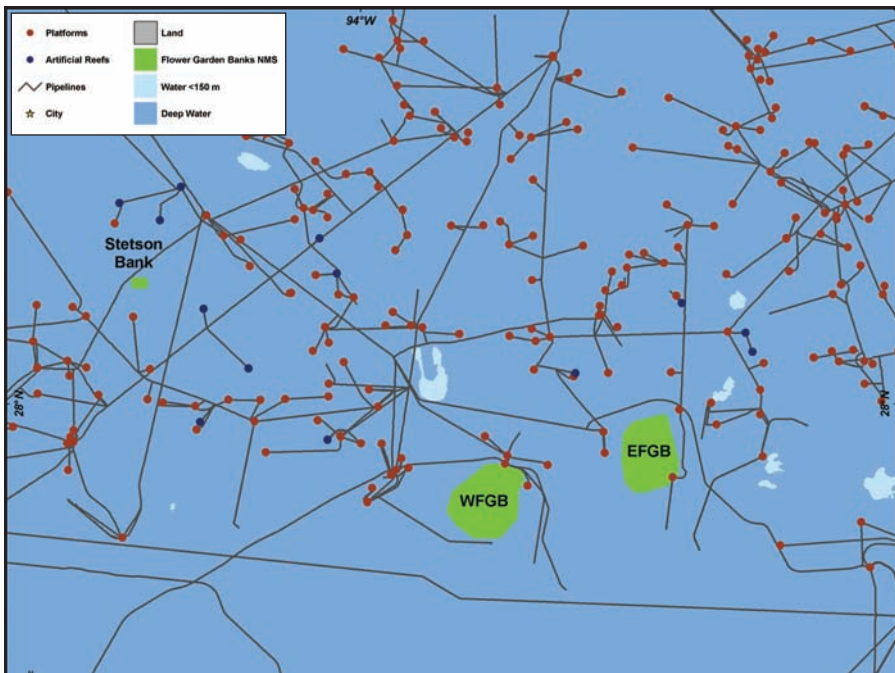


Figure 8.11. Oil and gas infrastructure in the vicinity of the FGBNMS. Blue circles indicate inactive platforms that have been cut off at depth and converted to artificial reefs. Map: A. Shapiro. Sources: D. Weaver; U.S. DOI-Minerals Management Service.



Figure 8.12. Gas platform HIA389A (W&T Offshore) is located within Sanctuary boundaries, within 1 mile of the coral cap. Photo: FGBNMS.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

East and West Flower Garden Banks, Long-Term Monitoring Project

Since 1989, the coral caps of the East and West Banks of the FGBNMS have been monitored annually through a contract funded cooperatively by the FGBNMS and MMS. Since 2002, the contract has been held by a group led by PBS&J, GeoMarine, Inc., and Dauphin Island Sea Lab. Monitoring of Stetson Bank is not included in the contract. The data presented below are from the long-term monitoring report through 2001. The most recent investigations (2002-2003) are currently in press and will be included in future reporting efforts.

The FGBNMS Long-Term Monitoring (LTM) Project is conducted within a 100 m² area on the reef cap, and evaluates water quality (temperature, salinity, light attenuation, pH, turbidity, DO₂), reef diversity, growth rates, long-term changes in individual coral colonies, accretionary growth, general coral reef community health, fish, lobster, and *Diadema* surveys (Figure 8.13). Water samples are analyzed for nitrogen, nitrate, nitrite, dissolved ammonia, soluble reactive phosphorus and total phosphorus, and chlorophyll A. It is realized that the 100 m² study site does not incorporate discreet zones found elsewhere in the coral reef area (e.g., *Madracis mirabilis* fields).

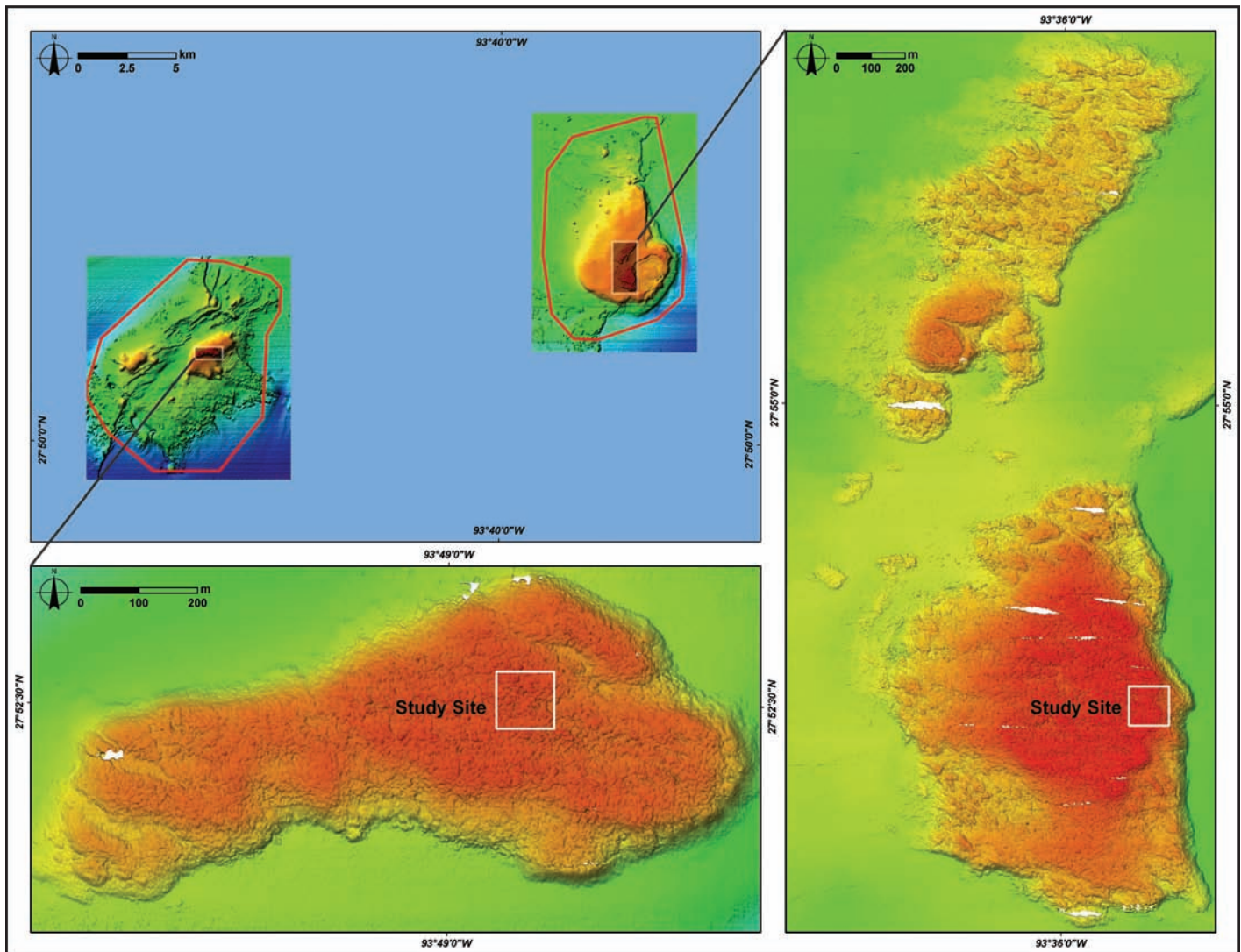


Figure 8.13. West and East FGB 100 m² study sites located on the coral caps (indicated in red). The coral caps represent less than 2% of the area within the Sanctuary boundaries. Map: A. Shapiro. Source: Gardner et al., 1998; D. Weaver.

Atlantic and Gulf Rapid Reef Assessment Surveys

Benthic and fish communities at one site on each of the East and West Banks were assessed using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol in August 1999.

Reef Environmental Education Foundation Fish Surveys

The Reef Environmental Education Foundation (REEF) conducts fish surveys annually at the FGBNMS using roving diver surveys. The surveys do not quantify the abundance or biomass of the fish community, but all observations are entered into the REEF database. Methods and data are available at <http://www.reef.org>.

Other Sanctuary Activities

In addition to the AGRRA and REEF programs which are summarized in Table 8.1, the FGBNMS supports (by providing shiptime on chartered or Sanctuary vessels) several researchers investigating a wide array of topics. In addition, the Sanctuary research team conducts an annual data collection cruise, but funding limitations have precluded data analysis to date. Sanctuary staff encourage recreational divers to submit observations of charismatic megafauna, such as sharks, rays, and sea turtles, as the observations are maintained in the Sanctuary’s database.

The most recent available data from the FGBNMS LTM Project and AGRRA surveys are presented below to characterize the status of reef ecosystems at the FGBNMS. The combination of these results best describes the status of the resources, with limitations as noted below.

Table 8.1. Coral reef ecosystem monitoring activities that occur at the FGBNMS.

ECOSYSTEM COMPONENT	PROGRAM	SOURCE
Water Quality	FGBNMS LTM	Most recent report: Dokken et al., 2003.
		Current contractor: PBS&J 2002-2003 report: Precht et al., in press
Benthic Habitats	FGBNMS LTM	Most recent report: Dokken et al., 2003.
		Current contractor: PBS&J 2002-2003 report: Precht et al., in press
	AGRRA	AGRRA Program: Pattengill-Semmens and Gittings, 2003.
Reef Fish	FGBNMS LTM	Most recent report: Dokken et al., 2003.
		Current contractor: PBS&J 2002-2003 report: Precht et al., in press
	REEF	REEF database (www.reef.org)
	AGRRA	AGRRA Program: Pattengill-Semmens and Gittings, 2003.

WATER QUALITY

East and West Flower Garden Banks, Long-Term Monitoring Project

Methods

YSI 6600 Datasondes are deployed at the reef crests of all three banks of the FGBNMS. Sensors log the following measurements at 30 minute intervals: temperature, salinity, photosynthetically active radiation (PAR) irradiance, pH, turbidity, and DO₂. Quarterly servicing is maintained (Figure 8.14), although more regular servicing is recommended. Servicing is inhibited by weather conditions and access to the site. Quarterly water sampling is conducted at the surface, midwater, and near bottom. A reference PAR irradiance sensor has historically been maintained on the gas platform HIA389A located within 2 km of the coral cap at the EFGB, although it is not presently collecting data.

Results and Discussion

Only the EFGB and WFGB are discussed here; Stetson Bank data has been collected, but not yet analyzed.

The mean PAR irradiance and corresponding values for -k were lower at the WFGB than at the EFGB during 1997-1999; however, it does not appear that these differences were statistically significant. Seasonal variation in light levels was clearly evident in the plot of PAR values recorded at the HIA389A Platform. Seasonal variation in PAR was present, but less coherent for values recorded by the instruments at the EFGB and WFGB. Data gaps are frequent due to equipment failure.

Between September 23, 2001 and November 2003, salinity, turbidity, dissolved oxygen, and pH, in addition to temperature and PAR, were continuously measured at 30 minute intervals. During this period, salinity at EFGB ranged from about 32-38 ppt; salinity at WFGB ranged from about 33-37 ppt. Sensor integrity is questionable for other parameters.

Seawater temperatures were obtained from the Hobo-Temp recording thermographs (Onset Instruments, Pocasset, Massachusetts) deployed on the reef crest of EFGB and WFGB. 2002-2003 data show minimum temperatures at the EFGB and WFGB as 19.06°C and 18.99°C, respectively. Maximum temperatures were 20.24 °C and 30.22 °C, respectively (Figure 8.14). Due to equipment failure of the sensor at the EFGB, no data was recorded from April to November 2000, or from May 15 to August 26, 2003 at that site.

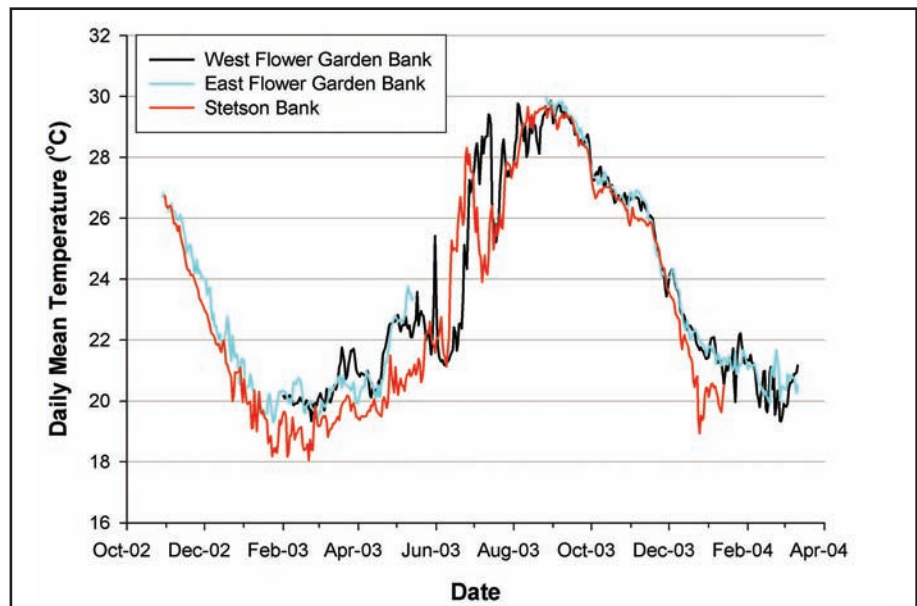
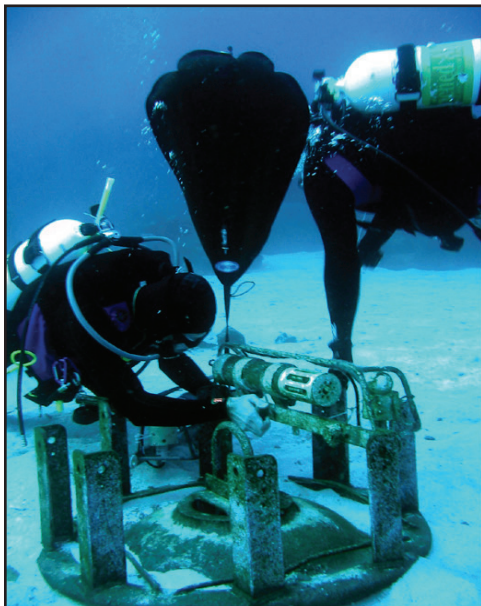


Figure 8.14. Left: YSI 6600 Datasonde quarterly servicing at the FGBNMS. Photo: PBS&J. Right: daily mean temperatures collected from October 2002 to April 2004. Source: Precht et al., in press.

BENTHIC HABITATS

East and West Flower Garden Banks, Long-Term Monitoring Project

Methods

A 100 m² study site has been established at both the EFGB and WFGB, and virtually all formal monitoring occurs within these areas. The following is a description of the methods outlined in the Statement of Work for the contracted monitoring effort co-funded by FGBNMS and MMS (MMS Document: NSL-GM-04-06; GOM-C4100, Section C). The monitoring includes several elements:

- Random Photographic Transects: 14 random photographic and/or digital video transects that are 10 m in length. Mean percent cover and standard deviation for each year and bank are calculated for coral species and other cover categories;
- Permanent Growth Stations: photographs of 60 permanent stations for monitoring growth of the scleractinian coral *Diploria strigosa*;
- Repetitive Quadrat Stations: 40 repetitive quadrat stations to detect and evaluate long-term changes in individual coral colonies. In addition to the initial 40 stations, nine repetitive quadrat stations have been established at the EFGB in coral reef habitat at deeper depths (30-40 m); and
- Sclerochronology: Cores of *Montastraea faveolata* coral colonies are taken biannually on each bank in odd numbered years to determine annual growth.

Results and Discussion

The results presented below are from the FGBNMS long-term monitoring report covering the years 1996-2001 (Dokken et al., 2003). A subsample of results from the 2002-2003 field season are also included where available (Precht et al., in press).

Random Photographic Transects—East Bank Community Composition and Structure (1996-2001)

From 1996 to 2001, mean percent cover of the *Montastraea annularis* complex increased, then increased again in 2003 on the WFGB, and decreased in 2002-2003 on the EFGB (Table 8.2). During the 2000-2001 and 2003 sampling years, coral cover ranged from 51.6-57.1% on the WFGB and 53.2-61.8% on the EFGB (Figure 8.15). The 2003 data reflect an overall reduction of coverage by the *Montastraea annularis* complex of at least 10%. Both *Porites astreoides* and *Millepora* spp. reflect higher percent coverages in 2003.

Total algal cover was greatest in 1999, then fell in both 2000 and 2001, and in the case of the WFGB, decreased by a factor of a third in 2003. *Diploria strigosa* was also highest during 1999 and likewise declined in both 2000 and 2001. Although a minor component, cover of *Siderastrea* sp. was highest (1.8%) in 1996 and fell to less than 1% in successive years. Cover of the remaining coral species as well as sponges remained relatively stable throughout the monitoring period of 1996 to 2001, but increased in coverage at both banks in 2003. Cover of reef rock was highest in 1998, the year before algal cover peaked, then declined. An additional parameter, calcareous bare turf was measured in the 2002-2003 data. This includes calcareous encrusting algae, including reds that may not be decipherable from bare space, and short turf algae <3 mm in size. This comprises a large component (at least 28% for both banks) in the 2003 data (Figure 8.15).

Table 8.2. Percent cover in 2000, 2001, and 2003 for random transects in the WFGB and EFGB. Standard deviations are in parentheses. Source: Dokken et al., 2003; Precht et al., in press.

SPECIES	WFGB			EFGB		
	2000	2001	2003	2000	2001	2003
<i>Agaricia agaricites</i>	0.3 (0.2)	0.3 (0.2)	0.24 (0.08)	0.2 (0.2)	0.4 (0.4)	0.33 (0.11)
<i>Agaricia fragilis</i>	0.007 (0.03)	0.003 (0.01)	0	0	0.1 (0.6)	0.01 (0.01)
<i>Colpophyllia natans</i>	3.6 (4.3)	2.8 (2.7)	2.17 (0.84)	2.6 (3.3)	2.6 (3.0)	3.29 (1.4)
<i>Diploria strigosa</i>	8.1 (6.7)	9.5 (5.8)	9.04 (2.68)	6.2 (2.8)	3.9 (4.1)	6.19 (1.55)
<i>Montastraea annularis</i> complex*	30.9 (11.6)	35.1 (12.0)	33.8 (4.31)	39.5 (9.6)	44.8 (12.9)	28.47 (2.98)
<i>Montastraea cavernosa</i>	5.8 (11.7)	2.1 (3.7)	2.67 (1.10)	4.8 (5.7)	3.6 (5.0)	4.24 (1.41)
<i>Scolymia</i> sp.	0.01 (0.02)	0.003 (0.009)	0.04 (0.03)	0.01 (0.02)	0.002 (0.009)	0.01 (0.01)
<i>Stephanocoenia mechelini</i>	0.9 (0.9)	0.3 (0.6)	0.96 (0.45)	0.1 (0.2)	0.2 (0.5)	0.76 (0.32)
<i>Mussa angulosa</i>	0.3 (0.6)	0.07 (0.2)	0.07 (0.04)	0.2 (0.4)	0.06 (0.3)	0
<i>Madracis</i> sp.	0.2 (0.4)	0.06 (0.1)	0.37 (0.29)	0.8 (2.3)	0.2 (0.3)	0.83 (0.34)
<i>Porites astreoides</i>	2.5 (1.6)	2.0 (0.9)	3.77 (0.46)	2.6 (1.7)	4.6 (2.7)	5.69 (0.98)
<i>Porites porites</i>	0.1 (0.6)	0.003 (0.01)		0.04 (0.08)	0.03 (0.1)	
<i>Siderastrea</i> sp.	2.0 (4.0)	0.002 (0.009)	2.04 (1.1)	0.03 (0.1)	0.2 (0.5)	0
<i>Millepora</i> sp.	0.7 (0.8)	0.7 (0.9)	1.94 (0.54)	1.3 (1.5)	0.9 (1.2)	2.23 (0.43)
Total Coral	51.6 (13.7)	53.1 (11.4)	57.13 (3.81)	58.3 (6.7)	61.8 (10.0)	53.2 (3.01)

**Montastraea annularis* complex is comprised of *M. annularis*, *faveolata*, and *franksi*

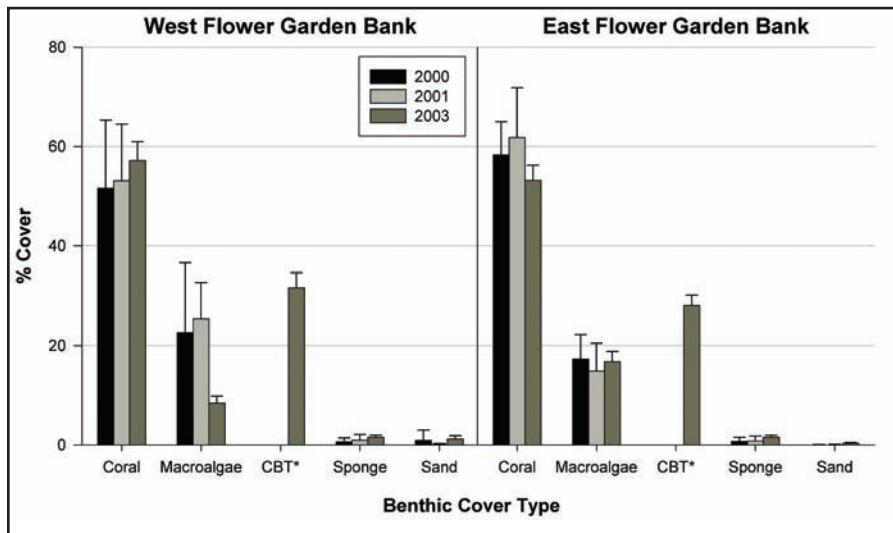


Figure 8.15. Benthic cover composition at the EFGB and WFGB from 2000-2003. Source: Dokken et al., 2003; Precht et al., in press.

Random Photographic Transects—East Bank, Comparisons Among Years (1996-2001)

ANOVA indicated that there were significant differences among years for five of the 13 coral species as well as total coral, total algae, and reef rock. Three overlapping, homogenous subsets of years were delineated for the *M. annularis* complex. The greatest difference was between the two years with highest cover, 2000 and 2001 and the two years with lowest cover, 1996 and 1997. Total coral, with four overlapping subsets, exhibited a similar pattern due to the dominance of the *M. annularis* complex in the community. Cover of

other coral species tended to overlap greatly with primary differences between the years of highest and lowest cover. Algal cover in 1999 was significantly higher than all other years and cover in 2000-2001 was significantly greater than 1996-1998. Reef rock was significantly higher than other years in both 1998 and 1999.

Random Photographic Transects—West Bank Community Composition and Structure (1996-2001)

Cover of the *M. annularis* complex and total coral increased slightly between 1996 and 2001. Total algal cover increased dramatically between 1997 and 2001. Although a minor component, cover of *Millepora* sp. was highest in 1997 and fell to less than 1% in each successive year. Also a minor component, *Siderastrea* sp. cover generally increased from 1996 to 2000, then dropped in 2001 to the lowest value recorded. Cover of the remaining coral species as well as sponges remained relatively stable throughout the monitoring period of 1996-2001. Cover of reef rock was highest in 1998 and 1999, declining by about 50% in each subsequent year.

Diversity was relatively stable between 1996 and 1999, increasing slightly in 2000, but then decreasing to a low in 2001. Evenness and dominance were fairly stable throughout the study period. Overall community similarity was 85%.

Random Photographic Transects—West Bank, Comparisons Among Years (1996-2001)

Only one coral, *Madracis* sp., a minor component of the coral community, exhibited significant differences among years. In 1999, *Madracis* spp. cover was significantly higher than all other years except 2000. There were also significant differences among years in algae cover and reef rock, with the delineated homogenous subsets representing the years of highest and lowest cover.

There were significant positive correlations between total coral cover and cover of the *M. annularis* complex, *D. strigosa*, and *M. cavernosa*. Cover of reef rock was significantly negatively correlated with algal cover. Runs tests indicated no significant trends only random variation in deviations above or below median for any species or reef component.

Permanent Growth Stations (2001-2002)

A total of 22 analyses were completed for the EFGB, with 15 advances and three retreats recorded. The remaining four cases could not be evaluated. A total of 13 analyses were completed for the WFGB, with eight advances, three retreats, and two cases that could not be evaluated. Assuming a null hypothesis of equal probabilities of advances and retreats, the two-tailed, cumulative binomial probability of 15 or more advances out of 18 at EFGB is $p=0.008$, which is significant at $\alpha=0.05$. The two-tailed, cumulative probability of eight or more advances out of 11 at WFGB is not significant at $p=0.227$. Combining the data from the two banks yields 23 advances, six retreats, and six cases that could not be evaluated. The two-tailed, cumulative binomial probability of 23 or more advances out of 29 is $p=0.002$, which is significant.

Permanent Growth Stations (2002-2003)

A total of seven analyses were completed for EFGB, with four advances and three retreats. A total of five analyses were completed for WFGB, with one advance, three retreats, and one case that could not be evaluated. The sample sizes were too small to perform the binomial test on the banks separately. Combining the data from the two banks yields five advances and six retreats, and the two-tailed, cumulative binomial probability of six or more retreats out of 11 is $p=1.000$, which is not significant.

There were significantly more advances than retreats at EFGB from 2001 to 2002, and this drove the overall significant result for 2001-2002. When considering both banks over both years of analysis, however, the results did not depart from the null expectation of equal numbers of advances and retreats. Although the samples for 2002-2003 were limited (a problem that the rehabilitation of stations has corrected for future years), we can conclude that the *Diploria* colonies may not have been growing, but they did not appear to be retreating either.

Repetitive Quadrat Stations

In general, the species composition and percent cover of the coral community in the 8 m² repetitive quadrats is similar to that found in the analysis of the random inside transects at EFGB. Overall, mean coral cover was about 7% lower than the inside random transects in 2000 and 10% in 2001; mean cover of the *M. annularis* complex was also 2-7% lower. *D. strigosa* mean cover was higher than the inside transects in both years. The mean cover of the remaining species was somewhat lower than that found in the inside transects, and four uncommon species, *Agaricia agaricites*, *A. fragilis*, *Scolymia* sp., and *Siderastrea* sp., were not found in the analysis of the 8 m² repetitive quadrats.

Sclerochronology

Four cores were taken from separate *Montastraea faveolata* colonies at the East Bank in August 2003. Estimated growth ranged from 0.77-1.07 cm from 1997-2003, with an overall mean of 0.92 cm \pm 0.11 (Precht et al., in press). The highest mean growth rate occurred in 1999-2000 and the lowest occurred in 2002-2003 (Figure 8.16). One core showed a partial mortality line in 1999; however, subsequent growth was established by surrounding polyps.

Four cores were taken from *M. faveolata* heads at WFGB in August 2003. Estimated growth ranged from 0.63-0.85 cm \pm 0.07, with an overall mean rate of 0.76 cm \pm 0.07 (Precht et al., in press). The highest mean growth rate occurred in 1999 and the lowest in 2002. Like the East Bank, one core showed partial mortality in 1999, but subsequent recovery was seen by surrounding polyps.

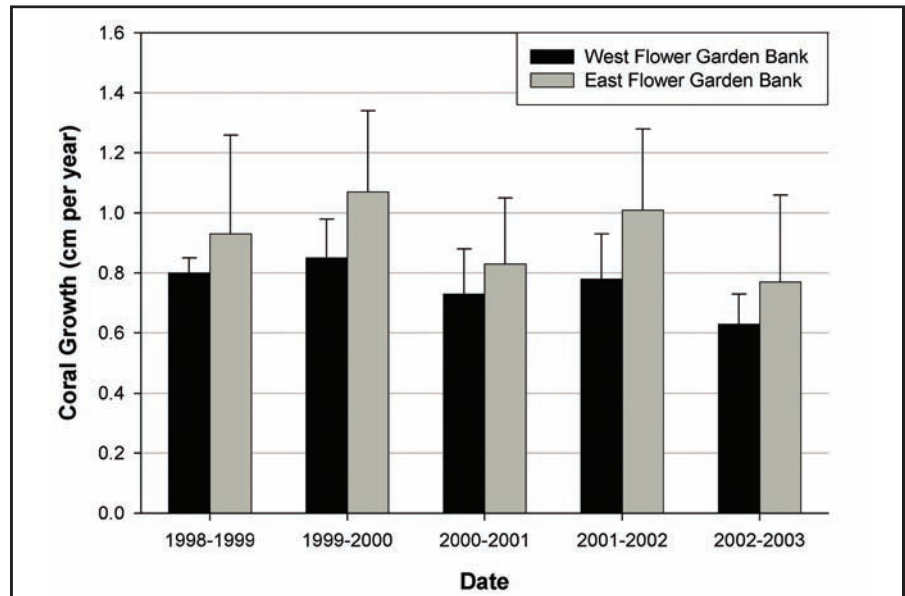


Figure 8.16. Mean annual coral growth (cm) with standard errors for 1998-2003 from *Montastraea faveolata* cores (n=4) collected at EFGB and WFGB in August 2003. Source: Dokken et al., 2003; Precht et al., in press.

Atlantic and Gulf Rapid Reef Assessment

Methods

A team of seven scientists and three REEF experts conducted the AGRRA surveys (Pattengill et al., 2000) on EFGB and WFGB from August 15-20, 1999, at depths between 18-25 m. At the EFGB, 160 coral colonies were surveyed, 67 algae quadrats examined, 15 roving diver fish surveys conducted, and 12 fish belt-transects conducted. At the WFGB 135 coral colonies and 55 algae quadrats were examined, 11 roving diver fish surveys conducted, and 12 fish belt-transects performed.

Results and Discussion

The AGRRA surveys revealed very healthy reefs with high coral cover, dominated by impressive, healthy, and large corals, little macroalgae, and abundant fish populations. At the EFGB and WFGB, the average coral cover was 53.9% and 48.8%, respectively. The reefs were dominated by relatively large mounding corals primarily in the genera *Montastraea*, *Diploria*, and *Colpophyllia*. This was reflected in the average coral diameters from EFGB and WFGB, 81 and 93 cm, respectively. The percent of recent coral mortality was very low (<2.5%) at both sites. Macroalgal cover was very low at both sites, however at EFGB, a cyanobacterial mat was observed among the algae. Minimal bleaching was observed. The widespread 1998 bleaching event did not occur at the Flower Garden Banks. Few incidences of disease were recorded in the transects but parrotfish bites on coral were common at both sites. Overall, these reefs, which exist at the northern limits of reef development, appear to be very healthy with stable populations of coral, little macroalgae, and robust fish populations.

Benthic Habitat Mapping

In addition to the activities listed above, attempts are currently underway to further characterize the benthos in the FGBNMS through bathymetric and benthic habitat mapping activities. High resolution bathymetric maps have been developed for approximately 3,932 km² of the northwestern Gulf of Mexico reefs and banks to date, including 1 m resolution bathymetric maps of the coral caps at EFGB and WFGB. In addition, georeferenced remotely operated vehicles (ROV) surveys completed in the past several years are providing valuable input for the creation of coarse benthic habitat maps for the entire Sanctuary, which will provide managers with essential information about the marine community. Sanctuary staff are working with other scientists from NOAA, particularly NOAA's Center for Coastal Monitoring and Assessment-Biogeography Team, to integrate FGBNMS map products with those developed for the Florida Keys and the U.S. Caribbean. Draft maps are scheduled for completion in fall 2005.

ASSOCIATED BIOLOGICAL COMMUNITIES

East and West Flower Garden Banks, Long-Term Monitoring Project

FISH

Methods

Fish counts were performed at both banks using stationary visual techniques for quantitatively assessing community structure of coral reef fishes (Bohnsack and Bannerot, 1986). A minimum of 24 surveys were performed at each bank to provide a statistically sound assessment of reef fish abundance and diversity. Survey sites were selected randomly from within the study location.

Results and Discussion

A mean of 51 fish species (SD=3.5) per year were observed at the EFGB and WFGB in 2002 and 2003. Fish abundances showed no significant differences between banks and years. The mean species richness per diver survey was shown to have a significant difference ($p=0.0243$) between the EFGB (16.72 species per diver survey) and the WFGB (18.55 species per diver survey). Only surveys at the WFGB proved to be significantly different ($p=0.026$) between years with 19.71 species per diver survey in 2003 and 15.72 species per diver survey in 2002. The observed species richness in 2002 at the EFGB and WFGB was 54 and 53 respectively, and 46 and 52, respectively in 2003.

The Shannon-Wiener index of diversity (H') is a common ecological measure of community structure that integrates the number and variety of species found in a given area or region. The diversity value (H') consists of both a richness measure (no. of species) and an evenness measure (how individuals are distributed among species).

Shannon-Wiener diversity indices are very similar at both banks in 2002 and 2003 (Table 8.3). The highest value was for WFGB in 2003 (1.19) and lowest for EFGB in 2003 (0.90). Diversity indices for 2002 are 1.14 and 1.16 for WFGB and EFGB, respectively. Index values for evenness (J')

were calculated for the fish communities at both banks in 2002 and 2003 as well. As mean richness values were statistically lower on the EFGB than the WFGB, and evenness values (J') were generally lower at EFGB than at WFGB, it follows that the overall diversity (H') would exhibit a similar pattern.

Expressed as density values (no. of fish/area), overall fish abundance for the EFGB and WFGB in 2002 was 82.78 and 73.29 per 100 m² respectively, and in 2003 was 157.53 and 84.62, respectively. The increase in density at the EFGB in 2003 was primarily attributed to the increased abundance of two species: *Clepticus parrae* and *Chromis multilineata*. Divers recorded 63.66 *C. parrae* per 100 m² at EFGB in 2003, which represents a large increase in density from 2002, when the observed density of *C. parrae* was 14.59 per 100 m². The observed density of *C. multilineata* also increased at EFGB from a value of 5.50 per 100 m² to 32.94 per 100 m². *Thalassoma bifasciatum*, *C. parrae*, and *Paranthias furcifer* were consistently among the top five most abundant fishes. *C. cyanea*, *C. multilineata*, *Stegastes planifrons*, and *S. partitus* were also among the most abundant fishes regularly encountered in diver surveys.

A mean of 21 families (SD=0.82) were recorded. Labridae, Pomacentridae, and Serranidae were consistently the three most abundant fish families observed at the Flower Garden Banks with densities ranging from 6.92 Serranids per 100 m² at the EFGB in 2002 to 70.74 Labrids per 100 m² at the EFGB in 2003. Pomacentrids, Serranids, and Labrids are also the three best represented families with 12, 10, and 6 species having been recorded for each, respectively.

Table 8.3. Shannon-Weiner diversity index (H') and Evenness values (J') for fish populations at EFGB and WFGB in 2002-2003. Source: Precht et al., in press.

INDEX	2002		2003	
	EFGB	WFGB	EFGB	WFGB
Diversity (H')	1.16	1.14	0.90	1.19
Evenness (J')	0.67	0.66	0.54	0.69

SEA URCHIN AND LOBSTER SURVEYS

Methods

Long spined urchin (*Diadema antillarum*) surveys were conducted to establish current population levels as a basis for comparison with future observations (Table 8.4). Surveys were conducted approximately 1.5 hours after sunset using site boundaries as transect lines. Two transects, each 100 m long and 2 m wide were surveyed using the same site boundary transect lines as those used for the video transects at each study site. Spiny lobster (*Panulirus argus*) and spotted lobster (*P. guttatus*) surveys were conducted in a similar manner.

Results and Discussion

For urchin and lobster counts, only descriptive data exist due to the low numbers observed. The *D. antillarum* populations continue to be depressed. No lobster data were presented by Dokken et al. (2003), and no lobster were reported during the surveys in 2002-2003 along the prescribed survey lines (Precht et al., in press).

Table 8.4. Average number of *Diadema antillarum* per m² on the EFGB and WFGB from 1996-2001. Source: Dokken et al., 2003.

YEAR	EFGB	WFGB
1996	No counts made due to sea conditions	0.0033 m ²
1997	No counts made due to sea conditions	0.0038 m ²
1998	0.023 m ²	No counts made due to sea conditions
1999	No counts made due to sea conditions	No counts made due to sea conditions
2000	0.018 m ²	0.030 m ²
2001	0.005 m ²	0.050 m ²

Atlantic and Gulf Rapid Reef Assessment (AGRRA)*Methods*

A team of seven scientists and three REEF experts conducted the AGRRA surveys on EFGB and WFGB from August 15-20, 1999. Details of the methods used are contained in Pattengill et al. (2000). The reef surveys were conducted at depths between 18-25 m. At the EFGB, 160 coral colonies were surveyed, 67 algae quadrats examined, 15 roving diver fish surveys conducted, and 12 fish belt-transects conducted. At the WFGB, 135 coral colonies and 55 algae quadrats were examined, 11 roving diver fish surveys conducted, and 12 fish belt-transects performed.

Results and Discussion

A total of 126 fish species were seen at EFGB and WFGB. One new record for the banks was recorded: sharptail eel (*Myrichthys breviceps*). The eel was seen at the WFGB, and had also been recorded on video earlier in the summer of 1999. Preliminary analyses of fish transect data showed high similarity between the EFGB and WFGB locations. Differences were seen in the butterflyfish and seabasses. The density of the reef butterflyfish (*Chaetodon sedentarius*) was two and a half times greater at the WFGB. Similarly, the density of graysby (*Epinephelus cruentatus*) at the WFGB was approximately twice that found at EFGB. Grunts were absent at both banks, a distinguishing characteristic of the Flower Garden Bank's fish assemblages. Average size of parrotfish and seabass was relatively high, reflecting the low fishing pressure.

Overall Condition and Summary of Analytical Results

The overall health of the reefs of the EFGB and WFGB continues to be described as stable, supporting approximately 50% coral cover comprised of primarily robust and massive species. Initial estimates of coral cover at the deep stations of the EFGB indicate upwards of 69% coral cover (W. Precht, pers. comm.). *Montastraea* spp. dominates the community, with *D. strigosa* also providing substantial cover. The stability of the system is evidenced by the continued high coral cover. Very little coral disease has been documented at the site. The FGBNMS appears to be insulated from mortality resulting from bleaching events. Bleaching

occurs, but minimally, and usually is followed by 100% recovery. Algae appear to play a balanced role in the reef habitat, and do not appear threatening to the coral component. Water conditions continue to be consistently good.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Regulations governing the FGBNMS are authorized under the National Marine Sanctuaries Act, as amended, 16 U.S.C. 1431, and are contained within the Code of Federal Regulations 15 C.F.R. 922, Subparts A, E, and L, available on the Internet at <http://www.sanctuaries.nos.noaa.gov/oms/omsflower/omsflowerpubdoc.html>. They are designed to protect the sensitive coral reef features of the Sanctuary. They prohibit anchoring of any vessel within the Sanctuary; mooring of any vessel greater than 100 feet on a Sanctuary mooring buoy; oil and gas exploration and development within a designated no activity zone (almost the entire Sanctuary); injuring or taking coral and other marine organisms; using fishing gear other than traditional hook and line; discharging or depositing any substances or materials; altering the seabed; building or abandoning any structures; and using explosives or electrical charges.

In 2001, the International Maritime Organization designated the FGBNMS as the world's first international no-anchor zone. This designation enhances the protection and awareness of the site by providing guidance and regulations at an international level.

Over the past five years, the Sanctuary research team has conducted dedicated ROV cruises exploring the portions of the Sanctuary below the depths of the coral reef cap. Over 35 species of antipatharians and gorgonians, as well as several species of azooxanthellate corals have been found in deeper waters. There is some indication that the coral reef areas and deepwater habitat may be important spawning areas for several species of grouper.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The coral reef ecosystem at the Flower Garden Banks is thriving, despite its location in the middle of one of the largest oil and gas fields in the world. Each year, Sanctuary staff review dozens of new requests for pipeline or platform installation within the MMS four-mile regulatory zone. One unresolved concern associated with oil and gas activities is the large quantities of contaminated water, or 'produced water,' that is generated during offshore oil platform operations. The effects of produced water on coral reef ecosystems are unknown and represent a significant knowledge gap that needs to be addressed in response to the expansion of oil and gas activities in the region.

Other substantial knowledge gaps exist, in part due to the difficulty of accessing this relatively remote location. While distance from shore may lessen some of the impacts attributed to recreational use, it also hampers monitoring of human activities, research with respect to recreational use of the area by divers and fishers, and enforcement of Sanctuary regulations. While some data on visitor use can be attained by a variety of remote methods such as overflights, satellite imagery, and remote radar systems, the Sanctuary needs to increase on-site observation, management, and enforcement.

The location of the Flower Garden Banks also makes the logistics involved in monitoring activities difficult and expensive, which limits the frequency of sampling and the total area able to be surveyed during data collection. Under the current methods, sampling points are limited to a 100 m² area in the shallowest part of the coral caps, which represents a fraction of the total area of the banks. Limitations in sampling frequency and spatial distribution of survey sites restrict scientists' analytical power to measure change with a sufficient level of confidence, especially when trying to account for adjacent reefs or banks. Addition of monitoring data from banks and reef areas in other parts of the Gulf of Mexico would help scientists understand the role of these banks in relation to coral reef ecosystems in the wider Gulf region.

Despite these limitations, the LTM Project results indicate that the EFGB and WFGB reefs are relatively pristine as compared to other Caribbean reef systems. Budget constraints have precluded the analysis of Stetson Bank monitoring data to date, but analysis of existing data is a priority for increasing management capability. Anecdotal and photographic observations made at Stetson Bank are noted (e.g., a recent algal bloom), but cannot be acted upon without quantitative evidence.

The observations indicating that FGBNMS is an important spawning area for several species of grouper warrants further investigation, and highlights the importance of considering a no-take marine reserve to protect the biodiversity of this region. While it is clear that the reefs of the FGBNMS are biologically and ecologically connected with the numerous reefs and banks found in the northwestern Gulf of Mexico, a newly described endemic wrasse (Weaver and Hickerson, in press) documented at all three banks of the FGBNMS illustrates the uniqueness on a local scale.

The FGBNMS harbors a close to pristine coral reef ecosystem. It is crucial that the status of this resource be maintained in its current condition. In a world of declining coral reef health, this site can be used as a standard for comparison to all other Caribbean coral reef systems, and may function as a source of recruits for neighboring regions.

It should be recognized that several reefs and banks that exist in the vicinity of the FGBNMS also harbor deep coral reef communities. These banks include Bright, Geyer, Sonnier, and McGrail Banks. No regulations currently protect these resources other than from the direct impacts from oil and gas activities.

REFERENCES

- Bohnsack, J. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41. 15 pp.
- Dennis, G.D. and T.J. Bright. 1988. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. *Bulletin of Marine Science* 43 (2): 280-307.
- Deslarzes, K.J.P. (ed.) 1998. The Flower Garden Banks (Northwest Gulf of Mexico): Environmental Characteristics and Human Interaction. OCS Report MMS 98-0010. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans. 100 pp.
- Deslarzes, K.J.P., and A. Lugo-Fernández. In press. Influence of terrigenous runoff on offshore coral reefs: An example from the Flower Garden Banks, Gulf of Mexico. In R.B. Aronson (ed.) *Geological approaches to coral reef ecology*. Springer-Verlag, New York.
- Ditton, R.B. and C.E. Thailing 2001. The Economic Impacts of Sport Divers Using the Flower Garden Banks National Marine Sanctuary. Department of Wildlife and Fisheries Sciences, Texas A and M University, College Station, TX. 11 pp. Available from the internet url: <http://lutra.tamu.edu/hdlab/downloads.htm>.
- Dokken, Q.R., I.R. McDonald, J.W. Tunnell, Jr., C.R. Beaver, G.S. Boland and D.K. Hagman. 1999. Long-Term Monitoring at the East and West Flower Garden Banks, 1996-1997. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. OCS Study MMS 99-0005. 101 pp.
- Dokken, Q.R., I.R. MacDonald, J.W. Tunnell, Jr., T. Wade, K. Withers, S.J. Dilworth, T.W. Bates, C.R. Beaver and C.M. Rigaud. 2003. Long-Term Monitoring at the East and West Flower Garden Banks, 1998-2001: Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans. OCS Study MMS 2003-031. 90 pp.
- Dunton, K. University of Texas Marine Science Institute, Port Aransas, TX. Personal communication.
- Fenner, D. 2001. Biogeography of Three Caribbean Corals (Scleractinia) and the invasion of *Tubastraea coccinea* into the Gulf of Mexico. *Bulletin of Marine Science* 69 (3): 1175-1189.
- Fenner, D. and K. Banks. 2004. Orange Cup Coral *Tubastraea coccinea* invades Florida and the Flower Garden Banks, Northwestern Gulf of Mexico. *Coral Reefs* 23: 505-507.
- Gardner, J.V., L.A. Mayer, J.E. Hughes Clarke and A. Kleiner. 1998. High-Resolution Multibeam Bathymetry of East and West Flower Gardens and Stetson Banks, Gulf of Mexico. *Gulf of Mexico Science* XVI 2: 128.
- Gittings, S.R. 1998. Reef Community Stability on the Flower Garden Banks, Northwest Gulf of Mexico. *Gulf of Mexico Science* XVI 2: 161.
- Gittings, S.R., K.J.P. Deslarzes, D.K. Hagman, and G.S. Boland. 1992. Reef coral populations and growth on the Flower Garden Banks, northwest Gulf of Mexico. pp. 1: 90-96. In: *Proceedings of the 7th International Coral Reef Symposium*.
- Gittings, S.R., T.J. Bright and D.K. Hagman. 1993. Protection and monitoring of reefs on the Flower Garden Banks, 1972-1992. pp. 181-187. In: R.N. Ginsburg (ed.) *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Healths, Hazards and History*. University of Miami.
- Hagman, D.K. and S.R. Gittings. 1992. Coral bleaching on high latitude reefs at the Flower Garden Banks, NW Gulf of Mexico. pp. 1: 38-43. In: *Proceedings of the 7th International Coral Reef Symposium*.
- Pattengill, C.V. 1998. The Structure and Persistence of Reef Fish Assemblages of the Flower Garden Banks National Marine Sanctuary. Ph.D. dissertation for Texas A and M University. 164 pp.
- Pattengill, C.V., S.R. Gittings, and T. Shyka. 2000. Flower Garden Banks National Marine Sanctuary – A Rapid Assessment of Coral, Fish, and Algae Using the AGRRA Method. *Marine Sanctuaries Conservation Series*. Available from the internet url: <http://www.sanctuaries.nos.noaa.gov/library/national/conseriesAGRRA.pdf>.
- Pattengill-Semmens, C.V. and S. R. Gittings. 2003. A Rapid Assessment of the Flower Garden Banks National Marine Sanctuary (Stony Corals, Algae and Fishes). pp. 500-511. In: E. Judith C. Lang (ed.) *Status of Coral Reefs in the Western Atlantic: Results of Initial Surveys, Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program*.
- Precht, W. PBSandJ, Miami, FL. Personal communication.

Precht, W., R. Aronson and K.J.P. Deslarzes. In press. Long-Term Monitoring at the East and West Flower Garden Banks, 2002-2003: Final Report. Office of Coast Survey (OCS) Study, Minerals Management Service (MMS). U.S. Dept. of the Interior, MMS, Gulf of Mexico OCS Region, New Orleans.

Rezak, R., T.J. Bright and D.W. McGrail. 1985. Reefs and Banks of the Northwestern Gulf of Mexico: Their Geological, Biological, and Physical Dynamics. John Wiley and Sons, New York. 259 pp.

Schmahl, G.P. and E.L. Hickerson. In press. Deep tropical coral reef communities in the northwestern Gulf of Mexico. In: Proceedings of the 10th International Coral Reef Symposium.

Sinclair, J. Department of the Interior, Minerals Management Service, New Orleans, LA. Personal communication.

U.S. Dept. of Interior (USDOI). 1996. Long-term monitoring at the East and West Flower Garden Banks. OCS Study MMS 96-0046. USDOI, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans. 77 pp.

Weaver, D.C. and E.L. Hickerson. In Press. *Halichoeres bureki*, A New Wrasse (Pisces: Labridae) from the Flower Garden Banks National Marine Sanctuary, Northwestern Gulf of Mexico, and a Review of Related Species in the Tropical Eastern Pacific and Western Atlantic Oceans. Gulf of Mexico Science.

Weaver, D.C., E.L. Hickerson and G.P.Schmahl. In press. Deep reef fish surveys by submersible on Alderdice, McGrail, and Sonnier Banks in the Northwestern Gulf of Mexico. In: J.C. Tayler (ed.) Emerging Technologies for Reef Fisheries Management. National Oceanic and Atmospheric Administration Professional Papers National Marine Fisheries Service.