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Long-Term Monitoring at the East and West Flower Garden Banks National Marine Sanctuary, 2009–2010

Volume 1: Technical Report

U.S. Department of the Interior
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Flower Garden Banks National Marine Sanctuary

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ABOUT THE COVER

The cover photograph features Marissa Nuttall, a NOAA scientific diver from the Flower Garden Banks National Marine Sanctuary, following a compass heading while laying out a random transect line at the East Flower Garden Bank long-term monitoring study site. Photograph by John Embesi (NOAA FGBNMS).

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EXECUTIVE SUMMARY

In more than 20 years of being continuously monitored, the coral reefs of the Flower Garden Banks National Marine Sanctuary have maintained high levels of coral cover, suffered minimally from hurricanes, coral bleaching, and disease outbreaks, and supported relatively diverse and abundant fish populations as well as other vertebrate and invertebrate species. No significant long-term changes have been detected in coral cover or diversity at the Flower Garden Banks during monitoring efforts that have taken place since 1988, and likely not since the first measurements were made in the early 1970s. During the 2009 to 2010 monitoring period, the analysis of monitoring data indicated that the East and West Flower Garden Banks were robust and productive. Based on the 2009 and 2010 data, the average coral cover on the Flower Garden Banks coral caps is nearly 57 percent.

Located 193 and 172 km (East and West Flower Garden Banks, respectively) offshore from Galveston, Texas, the banks are remotely located topographic features on the outer continental shelf in the Gulf of Mexico that are capped with reef-building corals. Relative to other coral reef systems in the Southeast and Caribbean region, the Flower Garden Banks (FGB) have a low diversity of stony corals, yet high coral cover (typically around 50%). The East Flower Garden Bank (EFGB) and West Flower Garden Bank (WFGB), along with Stetson Bank, comprise the Flower Garden Banks National Marine Sanctuary (FGBNMS). The reefs at these banks are afforded a certain measure of natural protection due to their depth underwater and geographic distance from land.

In recent years, however, warning signs of impacts from natural and anthropogenic sources have been documented. Increased incidence of bleaching events, invasive species, and perceived reduction in fish densities at the FGBNMS (though in many cases not measurable) are reasons for increased vigilance and perhaps concern for the future of the resources. The incidence and prevalence of disease and bleaching in comparison to other western Atlantic coral sites, however, are low. The recent invasion by lionfish in the Gulf of Mexico, which are native to the Indo-Pacific, raises yet another cause for concern for the health and future of the bank ecosystems at the FGBNMS. This monitoring report represents a milestone, as it documents baseline, or at least pre-invasion, ecosystem conditions before the invasion of lionfish creates phase shifts on the reefs.

The results of the 2009 to 2010 monitoring efforts, conducted in August 2009, and August through November 2010, illustrate the continued stability of the coral reef community and associated fish populations. Random transect results revealed high coral cover within study sites at both banks from 2009 to 2010, and coral cover was estimated at 53.35% ± 4.17 and 54.49% ± 3.69, respectively, at the EFGB, and 53.84% ± 3.73 in 2009 and to 65.95% ± 2.85 in 2010 at the WFGB. These results are consistent with previous monitoring efforts of high coral cover above 50% at the FGB (Dokken et al. 1999; Dokken et al. 2001; CSA 1996; Gittings et al. 1992; Aronson et al. 2005, Zimmer et al. 2010), highlighting the coral stability over time.

Based on the results of the random transect data, the *Montastraea annularis* species complex (*M. annularis, M. faveolata,* and *M. franksi*; Weil and Knowlton 1994) was the dominant component of coral cover at both banks; *M. franksi* was identified as the dominant species within the complex. *Montastraea annularis* species complex cover at the EFGB was estimated at 29.52% ± 12.99 in 2009 and 33.89% ± 3.84 in 2010. At the WFGB, cover was 27.25% ± 3.32 in 2009 and 45.98% ± 3.68 in 2010. *Diploria strigosa* was the next most abundant species during this period, with 10.08% ± 2.54 at the EFGB in 2009 and 9.38% ± 1.72 in 2010. The WFGB estimates were 10.84% ± 2.70 and 5.39% ± 0.94 for the two years.

In 2009 and 2010, macroalgae were more abundant than crustose coralline algae, fine turf algae, and bare rock (CTB), ranging from approximately 22–33% over both banks. The most dominant macroalgal cover was by fleshy algae, thick turf algae, and *Dictyota* spp. An ANOVA revealed significant effects of location (bank), and, overall, macroalgal cover was higher at the EFGB than the WFGB. The data for the EFGB was significantly different from that of the WFGB ($p<0.02$), suggesting variations between banks. Tukey–Kramer *a posteriori* comparisons also showed that macroalgal cover was significantly higher at the EFGB than the WFGB.

CTB was the second-ranked non-coral category of substratum cover, ranging from approximately 10–15% over both banks from 2009–2010. An ANOVA revealed significant differences between years ($p<0.02$), and overall, CTB cover was lower at the EFGB in 2009, but higher than the WFGB in 2010. Tukey–Kramer *a posteriori* comparisons also showed that CTB cover was significantly higher in 2009 than in 2010.

The Shannon-Wiener diversity index, H', was calculated from the species-specific coral cover data from each transect in 2009 and 2010. The Shannon-Wiener diversity values at the EFGB were H'= 0.97 in 2009 and H'=0.95 in 2010. The values at the WFGB were H'= 0.98 in 2009 and H'=0.88 in 2010. The low values of H' overall reflect the low diversity, yet high dominance by the *Montastraea annularis* species complex.

Sclerochronology was used to measure the accretionary growth rates of *Montastraea faveolata*. Annual growth of *M. faveolata* at the EFGB averaged 0.55 mm/year (sample range = 0.30–0.76). At the WFGB, annual growth averaged 0.69 mm/year (range = 0.33–0.97). When compared to the past three coring events (2003, 2005, and 2007), the 2010 growth rate data were not substantially different. However, average growth rates at the EFGB decreased slightly from 2003 to 2010, while growth rates from the WFGB have remained relatively stable.

Random photographic transects were completed within the boundaries of the designated 100 m^2 monitoring study areas on each bank. These areas were originally selected in 1988 because they appeared to be representative of the reef caps on each bank. Even now, over 20 years later, no inconsistencies among the reef character outside the designated study areas and the study areas themselves are apparent, suggesting that little long-term change is a critical component of ecosystem quality.

Lateral growth stations were photographed in 2009 and 2010 to measure changes in *Diploria strigosa* colonies. *Diploria strigosa* is important at the FGB because it is the second largest contributor to coral cover. Net growth was positive over the 2009 to 2010 monitoring period.

Repetitive stations were photographed in 2009 and 2010 to monitor changes in specific coral reef locations over time. Like other data, repetitive quadrat data showed that coral cover was consistently high during the 2009 to 2010 monitoring period, averaging around 72% for both banks in all years (note that these stations were not selected as locations that were necessarily representative of the larger reef caps, so percent cover is likely not representative either). Macroalgae and CTB cover showed reverse patterns between banks and the incidences of bleaching, paling, and fish biting were low (ranging from 0.00–2.77% of area assessed). There was no evidence of coral disease in any of the repetitive quadrats analyzed in 2009 or 2010. The coral assemblages remained stable at both banks, with the dominant corals being the *Montastraea annularis* species complex, *Diploria strigosa*, *Porites astreoides*, and *M. cavernosa*.

In the 32–40 m deep repetitive quadrats (105–131 ft) at the EFGB, coral cover was high, averaging approximately 81.96% between 2009 and 2010. The *Montastraea annularis* species complex and *M. cavernosa* were the dominant species in this depth range. CTB averaged 7.35%, and macroalgae averaged 10.42%.

The review of the 2009 and 2010 perimeter videos suggests that, in general, the coral condition along the perimeter lines at the EFGB and WFGB study sites was comparable to that observed in past perimeter videos. The coral communities displayed low levels of stress and high coral cover. The most distressed corals were affected by incidences of paling and bleaching at the WFGB in 2010, followed by fish biting. No evidence of coral disease was observed in the perimeter videos. During the 2009 to 2010 monitoring period, three tropical storms and two hurricanes occurred in the Gulf of Mexico, but there were few changes in community structure attributable to them.

In addition to the annual data collection protocols, notable biological and oceanographic events, such as wildlife observations, *Acropora* discoveries, and coral health were qualitatively assessed and documented. April 20, 2010 marked the beginning of the *Deepwater Horizon* explosion, oil spill, and subsequent response, where an estimated 53,000 barrels per day escaped from the well before it was capped. While the oil spill caused damage to wildlife and marine habitats elsewhere in the Gulf of Mexico, no visible oil or oil-related impacts were observed in or near the FGBNMS.

Water quality parameters including seawater temperature and salinity were recorded at the EFGB and WFGB using Sea-Bird 37-SMP MicroCAT datasondes (high-accuracy conductivity and temperature recorders designed for long-term oceanographic deployment) from 2009 to 2010. HoboTemp thermographs were attached to each of the Sea-Bird platforms as backup recorders of water temperature. High seawater temperatures were observed during the late summer months of 2010, exceeding the 30°C coral bleaching threshold.

Fish surveys were conducted using the Bohnsack and Bannerot (1986) method in 2009 and 2010. Fish surveys showed robust fish assemblages that were dominated by invertivorous fish, with healthy populations of herbivores, piscivores, and planktivores. An average of 57 fish species were observed per bank per year. Pomacentridae, Labridae, and Serranidae were the dominant fish families at both banks. Invertivores were the dominant fish guild, with Pomacentridae (damselfish) and Labridae (parrotfish and wrasses) representing the largest density. The size-frequency distributions of invertivores were non-normally distributed, with the majority of individuals being small damselfish. Interannual comparisons indicated generally stable assemblages; however, diversity measures were significantly different at the WFGB between 2009 and 2010. Following the pattern of coral species present at the FGB (low diversity compared to Caribbean reefs, but high coral cover), the fish assemblages reflect a similar trend of low diversity and high abundance (Pattengill-Semmens and Gittings 2003).

Sea urchin surveys documented very low densities of *Diadema antillarum* at the EFGB in 2009 (0.25 per 100 m^2) and 2010 (0.5 per 100 m^2). Higher densities were documented at the WFGB in 2009 (13.75 per 100 m^2) and 2010 (11.0 per 100 m^2). These populations have not recovered to pre-1984 levels, which were at least 140 per 100 m^2 at the EFGB and 50 per 100 m^2 at the WFGB (Gittings et al. 1998). No *Panulirus argus* (Caribbean spiny lobster) or *Panuliris guttatus* (spotted spiney lobster) were recorded along transects at the EFGB or WFGB.

The FGB coral reefs remain in good condition and productive in comparison to reefs throughout the region. This may be in part to their remote location. Continued monitoring will document long-term changes in condition and will be useful for management decisions and future research focused on the dynamics of the robust benthic communities and the fish populations they support.

CHAPTER 1.0: INTRODUCTION

1.1. CORAL REEF MONITORING AT THE FLOWER GARDEN BANKS NATIONAL MARINE SANCTUARY

The biotic assemblages of the Flower Garden Banks National Marine Sanctuary (FGBNMS) constitute a high coral and low algal cover reef community with a robust fish assemblage (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2001, 2003; Pattengill-Semmens and Gittings 2003; Precht et al. 2006; Zimmer et al. 2010). Although coral species richness is lower at the FGBNMS than on most Caribbean reefs, 31 species of scleractinian corals (including deep coral species) have been documented at the FGBNMS (Schmahl et al. 2008). No significant long-term changes have been detected in coral cover or diversity at the FGBNMS from 1988 to 2008 (Zimmer et al. 2010), and probably not since the first measurements were taken in the mid-1970s (Gittings, 1998). In more than 20 years of continuous monitoring, the coral reefs of the FGBNMS have maintained high levels of coral cover, suffered minimally from hurricanes, coral bleaching and disease outbreaks, and supported relatively diverse and abundant fish and invertebrate populations. Though the rest of the Caribbean has experienced declines in zooxanthellate scleractinian coral cover (Gardner et al. 2003) and subsequent increases in macroalgal cover, the FGBNMS remains a stable coral reef system in the western Gulf of Mexico. These reefs, therefore, represent a natural laboratory for understanding the factors influencing stability and change in reef systems. The importance of the FGBNMS as representative western Atlantic coral reefs has been substantially elevated by the regional decline of corals. Consequently, the risk of loss (or estimated loss value) would be elevated for the FGBNMS in the event of a severe industrial accident, expansion of the zone of influence of the Mississippi River, or other significant change in environmental conditions.

The long-term monitoring program was initiated in 1988 by the Minerals Management Service (now the Bureau of Ocean Energy Management [BOEM]) to insure protective measures regulating potential impacts of offshore oil and gas development in the area were effective. Gittings et al. (1992) established a single, 100 x 100 m study site at both the East and West Flower Garden Banks (EFGB and WFGB, respectively) to monitor benthic community structure from 1988 to 1991 using coral cover, relative dominance, species diversity, evenness, accretionary and encrusting growth rates, and water quality parameters as potential indicators of reef health. Comparisons between their 1988–1991 results and those of previous studies from 1978–1982 (Rezak et al. 1985) showed no significant differences in any of the parameters, suggesting some degree of ecological stability over the period examined. During this time, coral cover was approximately 50% and dominated by the *Montastraea annularis* species complex (25%) and *Diploria strigosa* (8%) (Gittings et al. 1992). Gittings et al. (1992) considered spills from oil tankers, discharges of mud and drill cuttings during oil and gas exploration and production, noise from seismic surveys, and accidents on platforms leading to spills to be the greatest localized threats to these reefs.

No significant changes in coral community structure were reported between 1992 and 1995 by CSA (1996). However, variation in percent cover of individual coral species was detected between banks and between sampling years: 1992, 1994, and 1995. Minor individual coral bleaching was documented in 1990, 1992, and 1994, while 1995 was the first main bleaching event documented at the FGB coinciding with seawater temperatures in excess of 30°C (Hagman and Gittings 1992; Dokken et al. 1999, 2001, 2003).

Montastraea cavernosa and *Millepora alcicornis* were the species most affected by bleaching, but post-bleaching mortality rates were low at 0.2%–2.8% (1992–1995) and were patchily distributed. The small-scale spatiotemporal variation reported by CSA did not appear to affect long-term landscape-scale trends in coral cover or composition.

Dokken et al. (1999, 2003) continued the monitoring effort from 1996 through 2001 and documented no significant changes in coral growth or condition at the 100 x 100 m study sites at the EFGB and WFGB. Biodiversity inventories were conducted for algae and mollusks: 73 species of algae were documented as well as over 230 species of mollusks (Dokken et al. 2001, 2003). Fish assemblages were also documented (Pattengill 1998).

Using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol in 1999, Pattengill-Semmens and Gittings (2003) observed high coral cover of approximately 50% at 20–28 m (66–92 ft), dominated by large coral colonies (mean diameter 81–93 cm or 32–37 in), with a level of partial colony mortality (recent and long-dead portions of colonies) of only 13%. In concordance with earlier findings, turf was the dominant functional group of algae, whereas macroalgae accounted for less than 10% cover (Pattengill-Semmens and Gittings 2003).

Continued monitoring of the study sites in 2002 and 2003 by Precht et al. (2006) highlighted the long-term stability of the coral reef communities. Coral cover was around 50% at both banks during those years, and no significant diseases were detected. The relative dominance of coral species also remained consistent with past findings. *Diploria strigosa* margins grew overall from 2001 to 2002, whereas a low sample size for 2002 to 2003 (due to replacement of monitoring stations in 2003) prevented firm conclusions during that time period. Repetitive quadrat data from 2002 and 2003 revealed low prevalence of paling and bleaching (<0.61%) and no evidence of disease. Planimetry results showed an increase in surface area of selected corals at both banks. Oceanic water quality conditions prevailed at both banks in 2002 and 2003; however YSI maintenance issues produced data gaps, particularly for turbidity and PAR. Fish populations continued to be robust; however, *Diadema* and *Panulirus* abundance remained low.

Zimmer et al. (2010) continued the monitoring effort from 2004 through 2008 and demonstrated continued stability of the coral reef community and associated fish populations at the 100 x 100 m study sites at the EFGB and WFGB. Coral cover averaged over 50% at both banks and the *Montastraea annularis* species complex remained the dominant component of coral cover.

On September 23, 2005 Hurricane Rita (Category 3, Saffir-Simpson Index) passed approximately 93 km (58 mi) from the EFGB on its route north to the mainland of the United States. Two months later, Precht et al. (2008) conducted a post-hurricane assessment and reported that approximately 10% of the coral in repetitive quadrat stations at the EFGB were bleached. This was the highest level of bleaching reported for the FGB since the bleaching event of 1995; however, there was no evidence of coral disease in any of the repetitive quadrats analyzed from 2004 through 2008. It should be noted that is was known the bleaching event was ongoing prior to the hurricane, but staff were not able to travel offshore to conduct a bleaching survey due to the storm. After Hurricane Rita passed through the Gulf of Mexico, the seawater temperature at the FGB dropped considerably which may have helped counteract the bleaching event.

On September 12, 2008, Hurricane Ike (Category 3, Saffir-Simpson Index) passed directly over the EFGB. To monitor changes in coral reef community structure due to the passage of Hurricanes Rita and Ike, repetitive 8 m² quadrats and perimeter video collected in November 2005 and November 2008, respectively, were assessed for hurricane damage. The results of the post-hurricane cruise conducted in November 2005 are published in a separate report (Precht et al. 2008). An estimated total area of approximately 2.3 m² of coral was missing from the study-site repetitive quadrat stations between June 2007 and November 2008 at the EFGB and WFGB, most likely due to Hurricane Ike. The greatest loss in terms of both the number of missing coral colonies and the total loss in area of coral cover occurred at the EFGB. Hurricane impacts (i.e., dislodged colonies of *Diploria strigosa*) were only observed in perimeter video at the EFGB. No obvious hurricane impacts were observed along perimeter lines at the WFGB. The observed hurricane impacts were likely an underestimate of the actual hurricane damages because 1) only a portion of the perimeter surveys were comparable between June 2007 and November 2008 due to the loss of some corner locations and shifts in line placement, and 2) the 2008 perimeter video was recorded at an angle of 90º to the substrate due to operator error (rather than at 45º as in previous surveys), providing a smaller area of view and fewer coral colonies for comparison.

1.2. THE FLOWER GARDEN BANKS NATIONAL MARINE SANCTUARY IN THE GULF OF MEXICO

1.2.1. Habitat Description

The Flower Garden Banks are located in the northwestern Gulf of Mexico and are part of a discontinuous arc of reef environments along the outer continental shelf (Rezak et al. 1985; Figure 1.2.1). These coral reef-capped banks are the largest calcareous banks in the northwestern Gulf of Mexico (Bright et al. 1985). They contain the northernmost coral reefs in North America (Bright et al. 1984). Although coral and non-coral dominated communities exist on neighboring banks (e.g., Sonnier Bank, Stetson Bank, McGrail Bank), the reefs at Cabo Rojo in Mexico are the nearest shallow-water, true coral reefs in the Gulf of Mexico.

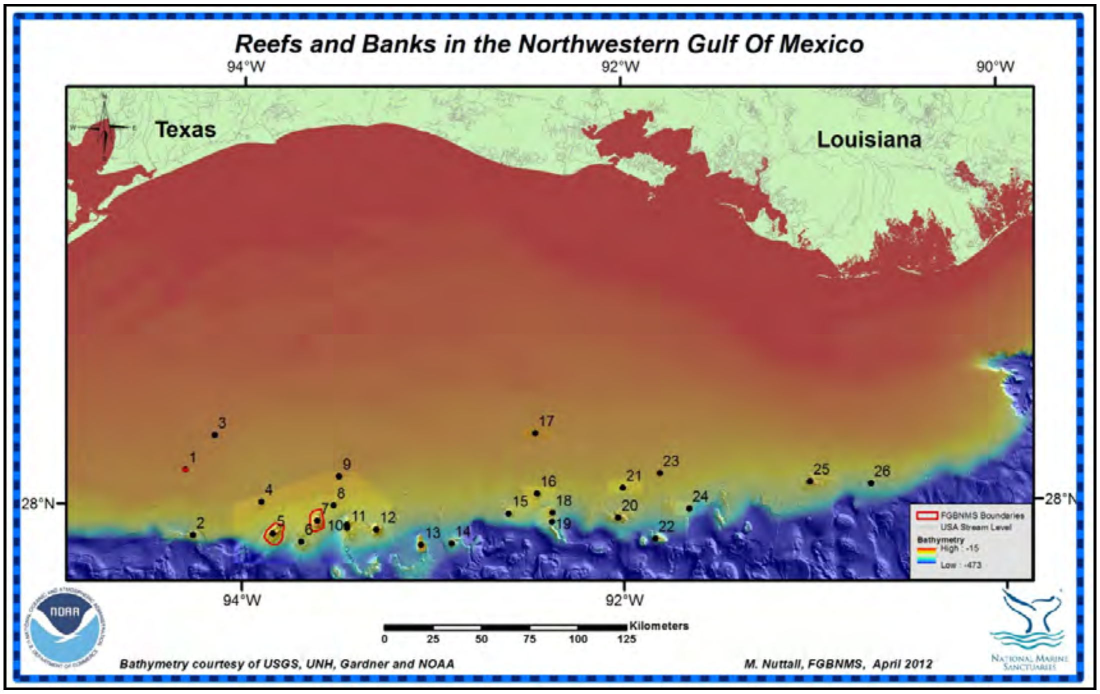


Figure 1.2.1. Map of the EFGB and WFGB in relation to the Texas-Louisiana continental shelf and other topographic features of the northwestern Gulf of Mexico.

1. Stetson Bank, 2. Applebaum Bank, 3. Claypile Bank, 4. Coffee Lump Bank, 5. West Flower Garden Bank, 6. Horseshoe Bank, 7. East Flower Garden Bank, 8. MacNeil Bank, 9. 29 Fathom Bank, 10. Rankin Bank, 11. 28 Fathom Bank, 12. Bright Bank, 13. Geyer Bank, 14. Elvers Bank, 15. McGrail Bank, 16. Bouma Bank, 17. Sonnier Bank, 18. Rezak Bank, 19. Sidner Bank, 20. Parker Bank, 21. Alderdice Bank, 22. Sweet Bank, 23. Fishnet Bank, 24. Jakkula Bank, 25. Ewing Bank, 26. Diaphus Bank. Red lines represent sanctuary boundaries (NOAA/FGBNMS).

The large-scale topographic features of the FGBNMS were created by geologic activity associated with salt diapirs of the Jurassic Louann Formation and consequent loading and uplifting of sedimentary rocks (Rezak 1981). Many such diapirs exist in the northern Gulf of Mexico and dozens form substantial submerged banks. The caps of some of the banks extend into the photic zone in clear oceanic waters, where conditions are ideal for colonization by species of corals, algae, invertebrates, and fish typical of coral reefs found in the Caribbean and western Atlantic (Figure 1.2.2). Although coral species richness is lower at the FGBNMS than on most Caribbean reefs, 31 species of scleractinian corals have been documented at the FGB (Schmahl et al. 2008) and 298 species of tropical Atlantic fish have been reported sanctuary wide, including the deepwater communities (Hickerson, unpublished data). Oceanic salinity conditions prevail at the FGBNMS and range from 34 to 36 PSU, with water temperatures ranging from 18°C (in mid-February) to 30°C (in late August). Water clarity at the banks is excellent (commonly 30 m or more) providing ample light to photosynthesizing organisms.

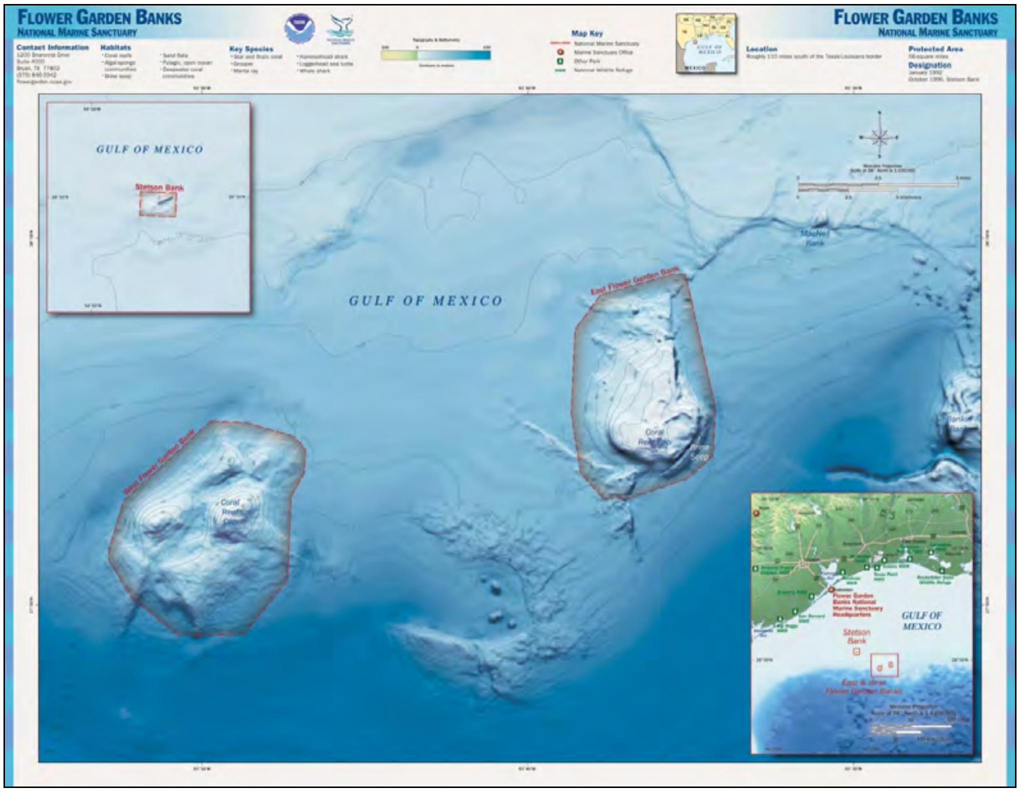


Figure 1.2.2. Topographic contour map of the FGBNMS (NOAA/FGBNMS).

1.2.2. The East and West Flower Garden Banks

The EFGB (27º 54.5' N, 93º 36.0' W) is a pear-shaped dome located approximately 193 km (120 mi) southeast of Galveston, Texas. The EFGB is 8.7 by 5.1 km (5.4 by 3.2 mi) in size, sloping from its shallowest point at 17 m (55 ft) to the terrigenous mud seafloor at a depth of 100–120 m (330–390 ft). The eastern and southern edges of the bank slope steeply whereas the northern and western edges descend more gently (Figure 1.2.3). The WFGB (27º 52.4' N, 93º 48.8' W) is an oblong-shaped dome located 20 km (12 mi) west of the EFGB and 172 km (107 mi) southeast of Galveston. It is 11.0 by 5.0 km (6.8 by 5.0 mi) in size and larger than the EFGB (Figure 1.2.4). The two peaks that comprise the WFGB are aligned along an east-west axis. The WFGB study site is located on the eastern peak, which is 18 m (59 ft) at its shallowest. Coral species diversity at both banks is low, with 31 species from 18 genera represented (Schmahl et al. 2008), compared to 67 species found on some Caribbean reefs (Goreau and Wells 1967). Shallow-water gorgonians and live acroporids have not been reported at the Flower Garden Banks in historical surveys. However, one colony of *Acropora palmata* was discovered in 2003 at the WFGB, but is in decline due to stressors such as damselfish predation, algal growth, etc. Another living colony of *A. palmata* was discovered at the EFGB, southeast of the study site in 2005 (Zimmer et al. 2006) and has a resident damselfish and minimal tissue loss.

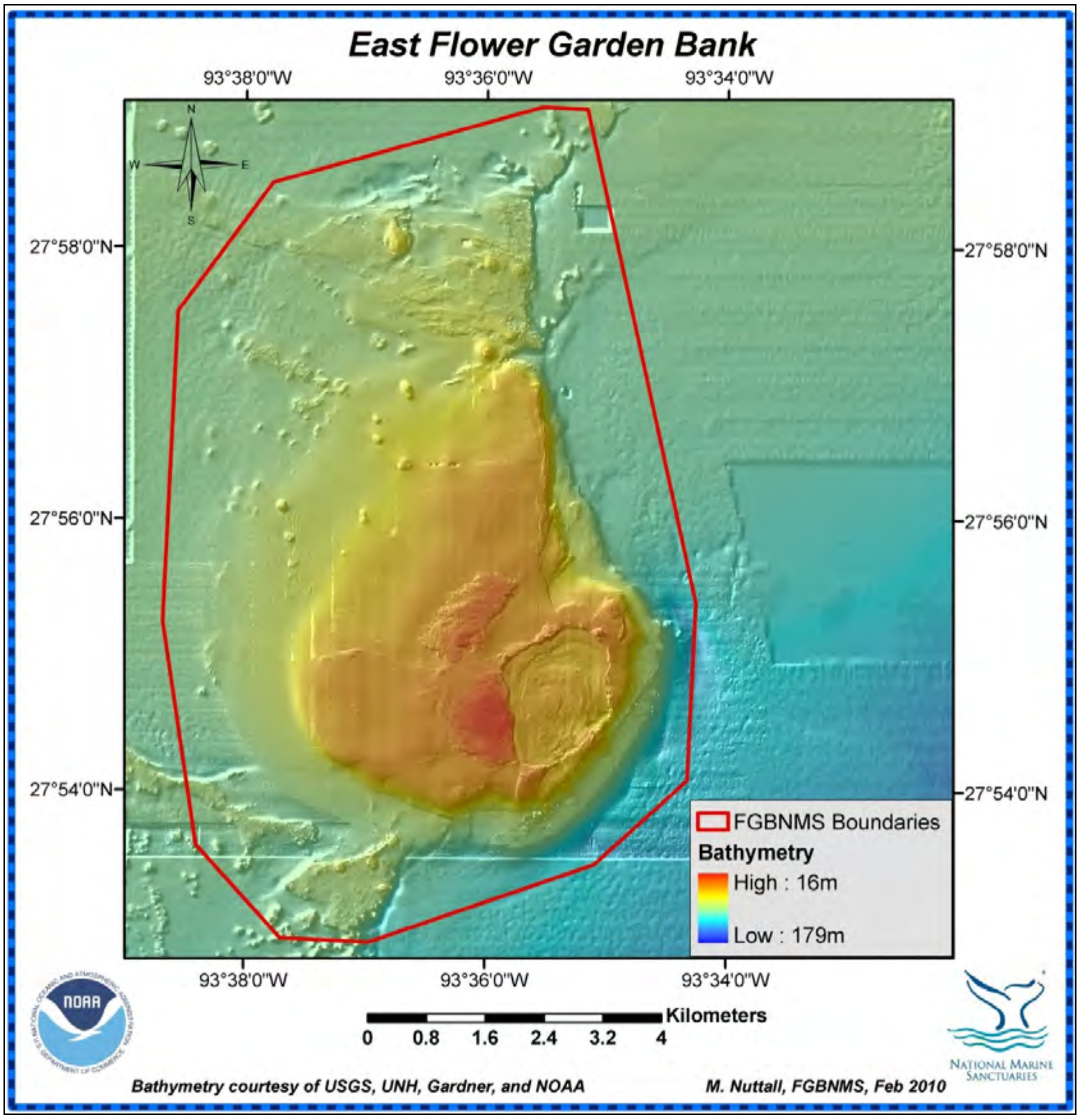


Figure 1.2.3. Bathymetric map of the EFGB (NOAA/FGBNMS).

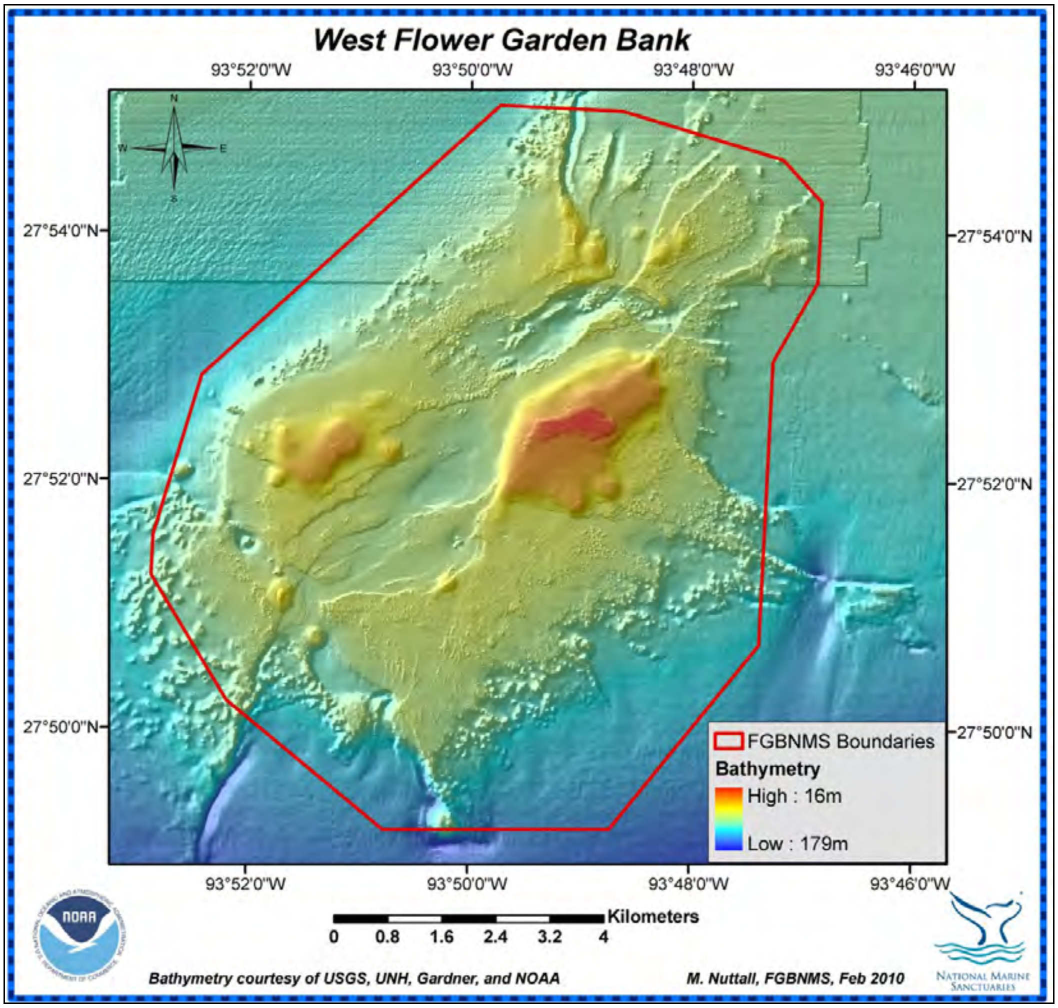


Figure 1.2.4. Bathymetric map of the WFGB (NOAA/FGBNMS).

Five habitat zones have been delineated at the EFGB and WFGB. This zonation scheme was updated by Schmahl et al. (2008) and includes the coral reef zone, the coral community zone, the coralline algal zones (which consist of coralline algal reefs and/or algal nodules), the deep coral zone, and the soft bottom zone. All monitoring at both banks was conducted within the coral reef zone.

1.3. BOEM AND FGBNMS PROTECTIVE MEASURES

Oil and gas activity in the vicinity of the FGBNMS has been ongoing since the 1970s. The former Minerals Management Service (MMS), of the U.S. Department of the Interior (USDOI), has regulated the development of the oil and gas industry on the Gulf of Mexico outer continental shelf. In 2010, MMS was reorganized and renamed the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE). In October 2011, the agency was reorganized and the agency partnering in this monitoring effort is now called the Bureau of Ocean Energy Management (BOEM).

The first coral reef assessment of the FGB took place at the WFGB in 1972 (Bright and Pequegnat 1974). In 1973, BOEM (then the Bureau of Land Management) conducted a program of protective activities at the FGB coral reefs and sponsored numerous studies of the banks. The Topographic Features Stipulation (since 1973) was designed to protect sensitive, biological resources in the northwestern Gulf of Mexico, from the adverse effects of routine oil and gas activities (USDOI, MMS 2002) and in particular, from the discharge of drilling effluents. Since 1983, the stipulation has protected the biota of the FGB from physical damage associated with oil and gas activities including anchoring and rig emplacement, and potential toxic and smothering effects from drilling muds and cuttings discharges (USDOI, MMS 2002). The Stipulation defines a No Activity Zone (NAZ) around each of the banks using boundaries based on the "¼, ¼, ¼ system", where lease blocks are divided into smaller sections by successively breaking each section into quarters (USDOI, MMS 1998). The boundary of the NAZ overlaps the 100–120 m isobaths (328-394 ft) at the WFGB and the 100–130 m isobaths (328–427 ft) at the EFGB. No oil or gas structures, drilling rigs, pipelines, or anchoring are allowed within the NAZ. The Stipulation also defines a "4 Mile Zone" outside of the NAZ, within which operators are to shunt all drill cuttings and drilling fluids to within 10 m (33 ft) of the seafloor. Note that the FGB are the only topographic features with a NAZ defined by the ¼, ¼, ¼ system. The NAZ of all other BOEM protected banks follow defined isobaths surrounding the bank.

In addition to the protections provided by the BOEM, the FGB were designated a United States National Marine Sanctuary in 1992 (Code of Federal Regulations, 15 CFR Part 992, Subpart L, Section 922.120). While certain exceptions exist for oil and gas operations, the FGBNMS regulates, restricts and prohibits:

(1) anchoring or mooring of all vessels within the sanctuary boundaries;
(2) discharge of any material or matter within the sanctuary boundaries;
(3) any alteration of the seabed within the sanctuary boundaries;
(4) any injury or removal or attempt of injury or removal of any living or non-living sanctuary resource;
(5) taking of marine mammals and sea turtles;
(6) possessing or using within the sanctuary boundaries any fishing gear except conventional hook and line gear; and
(7) possessing or using explosives within the sanctuary boundaries or releasing electrical charges within the sanctuary boundaries.

In July of 2001, the United States delegation to the International Maritime Organization (IMO), submitted a proposal to ban anchoring in FGBNMS for vessels greater than 30.48 m (100 ft). The IMO, out of concern for impacts to corals, modified the United States' proposal to prohibit all anchoring, but vessels 100 ft and under would be allowed to moor using existing sanctuary mooring buoys. The new international measure also ensured that no-anchoring zones are marked on all charts internationally. Code of Federal Regulations, 15 CFR Part 922.122 amended sanctuary regulations to align with IMO no-anchor rule within the sanctuary.

From 1988 to 1995, the BOEM monitored the FGBNMS coral reefs to detect any incipient changes that may be caused by oil and gas activities, as well as by other disturbances (Gittings et al. 1992; Gittings 1998). From 1996 until 2008, the FGBNMS and the BOEM partnered to continue the long-term monitoring of the FGB through a competitive contract. Since 2009, the FGBNMS has conducted the long-term monitoring and the BOEM continues to support half of the monitoring effort through an interagency agreement contract with the FGBNMS. The decision to take on this contract in-house was driven mainly by the acquisition of the FGBNMS research vessel (R/V) *Manta*. This vessel was task-designed, and allows the FGBNMS to be efficient and effective in its research abilities. The FGBNMS has also built up a team of NOAA scientific divers and researchers to conduct both the field work and analysis of the monitoring data.

1.4. *DEEPWATER HORIZON*

On April 20, 2010 *Deepwater Horizon*, a semi-submersible offshore drilling rig operating in lease block Mississippi Canyon 252, exploded; this resulted in the deaths of eleven people. More than 170 million gallons of crude oil were released into the Gulf of Mexico over a three-month period (NOAA 2012). Over 1 million gallons of dispersant were used, mostly Corexit 9500. On July 15, 2010, the leak was stopped by capping the gushing wellhead after it had released about 4.9 million barrels of crude oil. An estimated 53,000 barrels per day escaped from the well before it was capped (McNutt et al. 2011). On September 19, 2010, the relief well process was successfully completed, and the federal government declared the well to be successfully plugged. The *Deepwater Horizon* explosion resulted in the largest accidental marine oil spill in the history of the United States petroleum industry.

NOAA acted as the lead science support agency to the United States Coast Guard during the spill response. The spill site was approximately 520 km (323 miles) from the EFGB (Figure 1.4.1.), but because of the size of the spill, the potential for impact to the resources of the sanctuary was of great concern. As part of the National Resource Damage Assessment (NRDA) activities, FGBNMS personnel were assigned to the shallow and deep water coral response groups. In addition, semi-permeable membrane devices (SPMDs) were deployed at the EFGB and WFGB, as well as Stetson and Sonnier Banks.

While the oil spill caused damage to wildlife and marine habitats in other areas of the Gulf of Mexico, no visible oil or oil-related impacts have been observed in or near the FGBNMS. Furthermore, no hydrocarbon signatures were found in SPMDs at the FGBNMS. Nevertheless, the long-term monitoring data (including previous SPMD data) would have provided a valuable baseline from which impacts could have been detected, if they occurred.

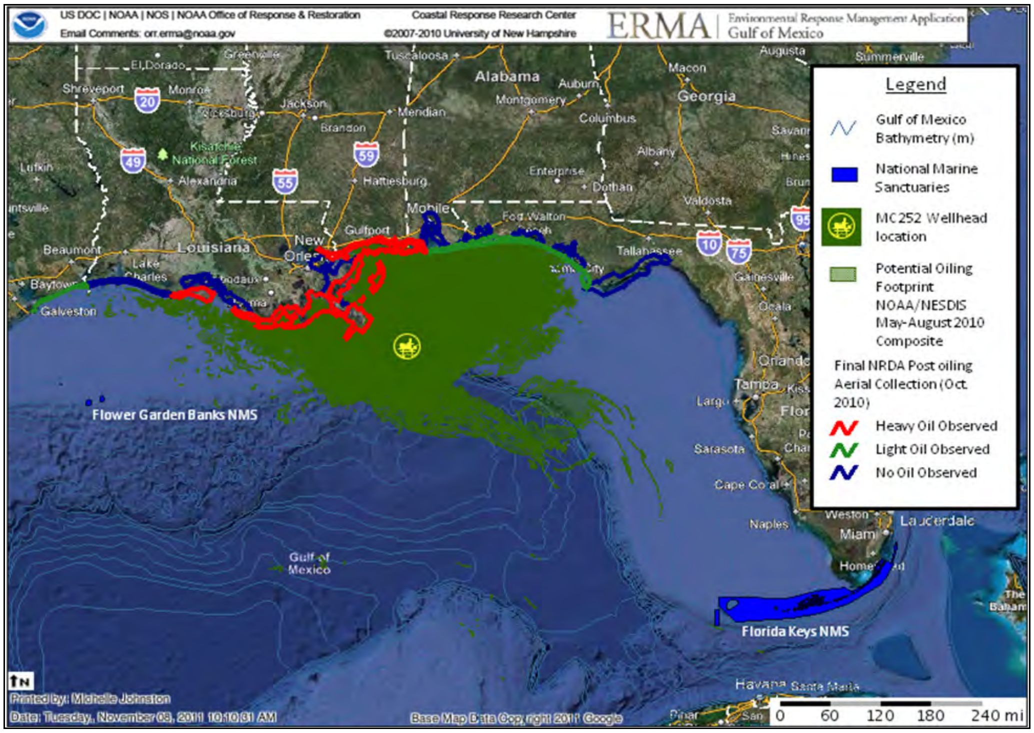


Figure 1.4.1. Map of the location of the *Deepwater Horizon* site in relation to the FGBNMS, including the maximum extent of observed oil from the spill (NOAA).

CHAPTER 2.0: STUDY SITES

2.1. STUDY SITE METHODOLOGY

The FGB are located roughly 190 km (118 mi) offshore and are submerged in water deeper than 18 m (59 ft). The monitoring effort was conducted from the NOAA R/V *Manta*. The benthos (with an emphasis on corals and algae) was examined along videographic transects and stationary repetitive photoquadrats. Sclerochronology was used to document the accretionary growth rate of specific coral colonies, and photography was used at permanent stations to monitor the lateral growth of corals. General aspects of coral condition were documented along perimeter lines at the EFGB and WFGB. During each annual monitoring cruise, observations of general coral reef health, as well as notable biological and oceanographic events were qualitatively assessed and documented. Water quality was assessed to characterize the reef cap and water column environment of the FGBNMS. Fish surveys were conducted at randomly located stations and sea urchin and lobster surveys were conducted along the study site perimeter lines.

2.1.1. 100 x 100 m Study Sites

Data were collected within the 100 x 100 m study sites at the EFGB and WFGB in 2009 and 2010 (Table 2.1.1). Originally established in 1988, the general locations of the study sites are marked by permanent mooring buoys: FGBNMS permanent mooring No. 2 at the EFGB (27° 53’ 35.80” N, 93° 38’ 23.90” W) and mooring No. 5 at the WFGB (27° 52’ 50.86” N, 93° 52’ 25.34” W). Figures 2.1.1 and 2.1.2 depict the topography of the EFGB and WFGB, respectively, along with the locations of the 100 x 100 m study sites. Figures 2.1.3 and 2.1.4 depict the mooring locations at EFGB and WFGB, respectively. Headings to corners from the mooring u-bolts were used to locate the corners (Table 2.1.2). Divers installed measuring tapes to temporarily mark the perimeters of the study sites and diving reels were used to mark the north/south and east/west centerlines (hereafter referred to as the “crosshairs”). Establishment of the perimeter and crosshairs divided each 100 x 100 m study site into four quadrants. The lines aided divers in orientation/navigation and they allowed for efficient completion of monitoring tasks. Each dive team was supplied with detailed underwater maps of each study site. Master maps were updated on the dive vessel with new data, including station numbers, locations, replacements, and revisions. These revisions are reflected in the current site maps (Figures 2.1.5 and 2.1.6).

Table 2.1.1.

Cruise Dates at the EFGB and WFGB for 2009 and 2010

EFGB	WFGB
August 2009	August 2009
August 2010	August 2010
	October 2010
	November 2010

Table 2.1.2.

GPS Coordinates for the EFGB and WFGB Study-Site Corner Markers

EFGB			WFGB		
Corner	**North**	**West**	**Corner**	**North**	**West**
NE	27º54'32.8	93º35'48.1	NE	27º52'31.8	93º48'53.6
NW	27º54'32.2	93º35'51.6	NW	27º52'31.5	93º48'56.9
SE	27º54'29.6	93º35'48.6	SE	27º52'28.7	93º48'53.2
SW	27º54'30.1	93º35'52.1	SW	27º52'28.5	93º48'56.8

Metal rods were previously installed in the reef to mark the permanent monitoring stations. There are two types of permanent monitoring stations within the study sites: (1) lateral growth stations on *Diploria strigosa* colonies, which are marked by two short rods per station; and (2) repetitive quadrats, the centers of which are marked by 0.5 m (1.6 ft) tall rods. Eighty repetitive quadrats and 120 lateral growth stations were maintained at the EFGB and WFGB.

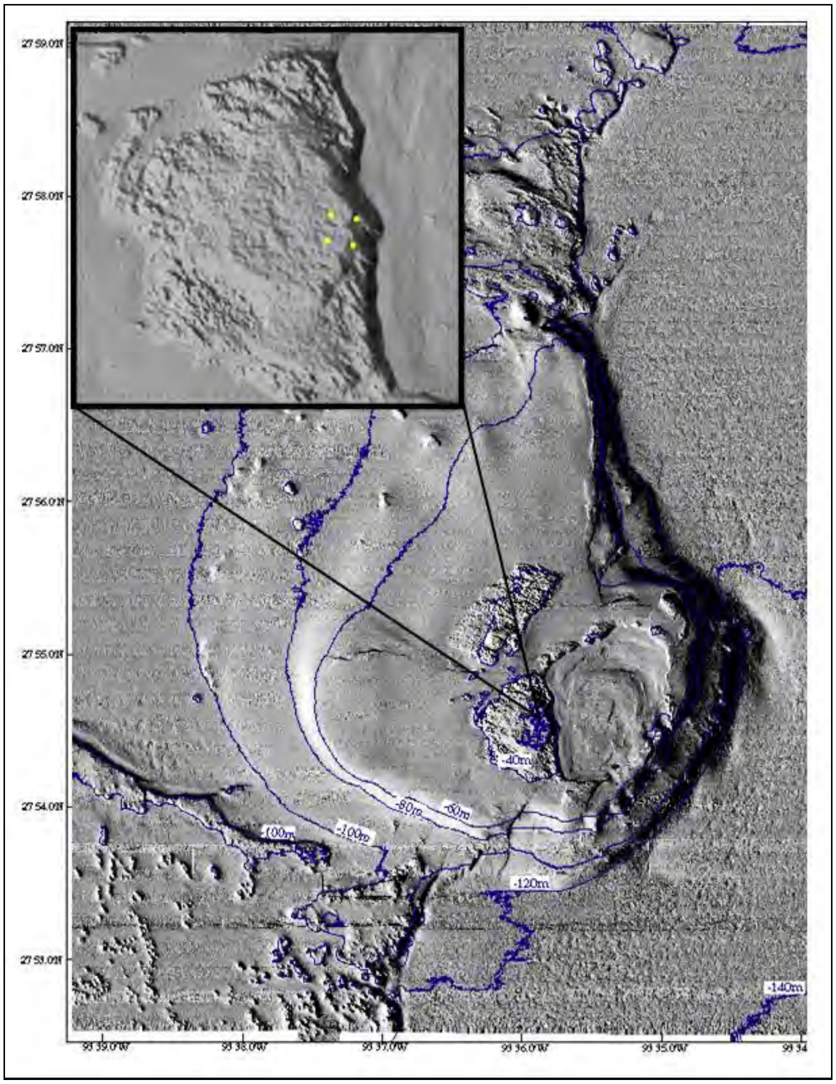


Figure 2.1.1. Topographic map of the EFGB. Inset shows the locations of the corners of the study site (USDOI/GS 2001).

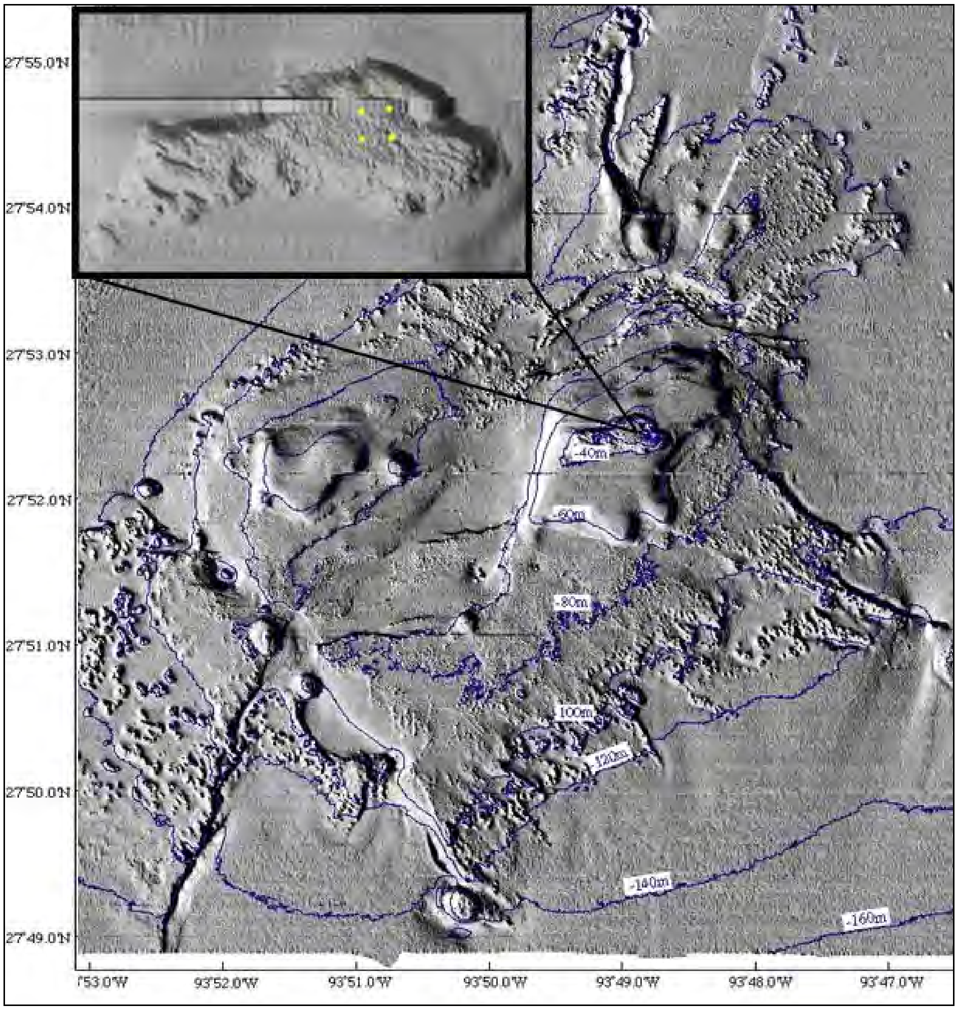


Figure 2.1.2. Topographic map of the WFGB. Inset shows the locations of the corners of the study site (USDOI/GS 2001).

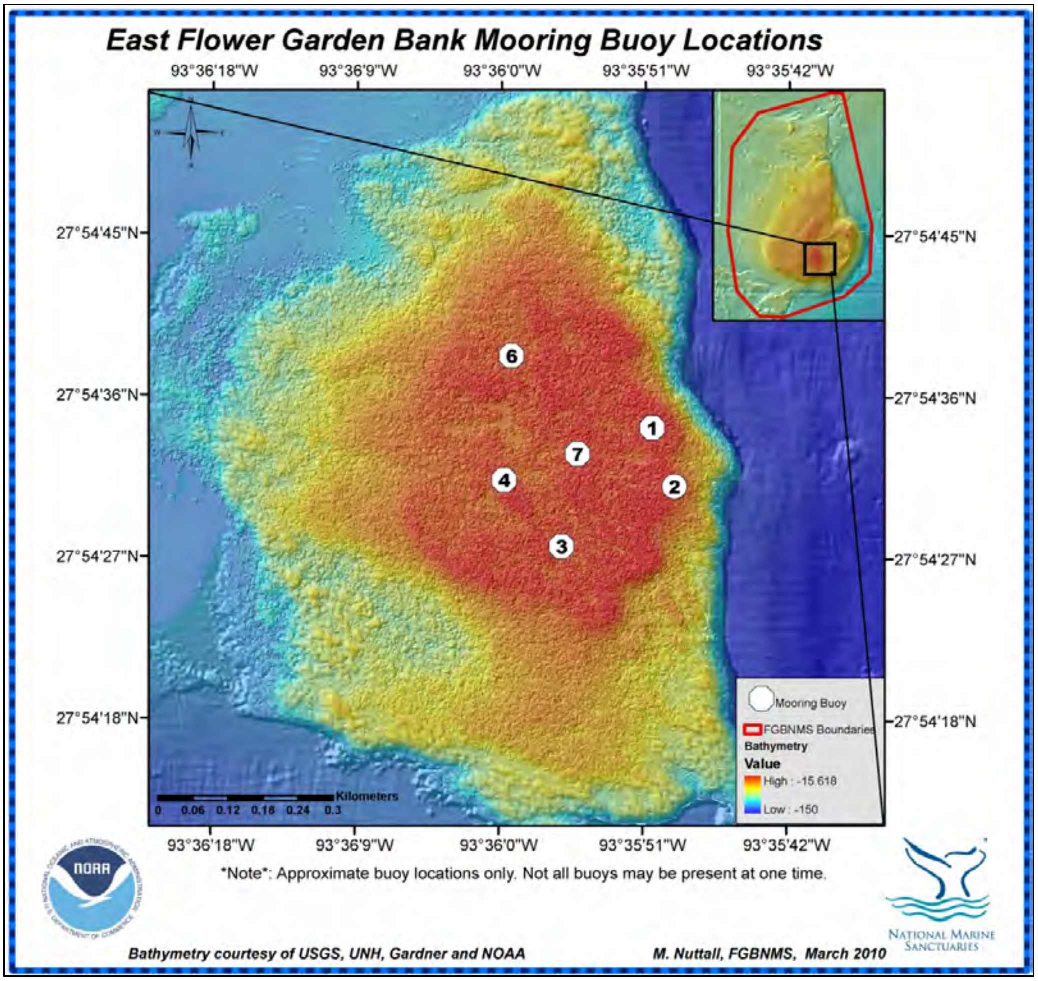


Figure 2.1.3. Locations of EFGB mooring buoys (NOAA/FGBNMS).

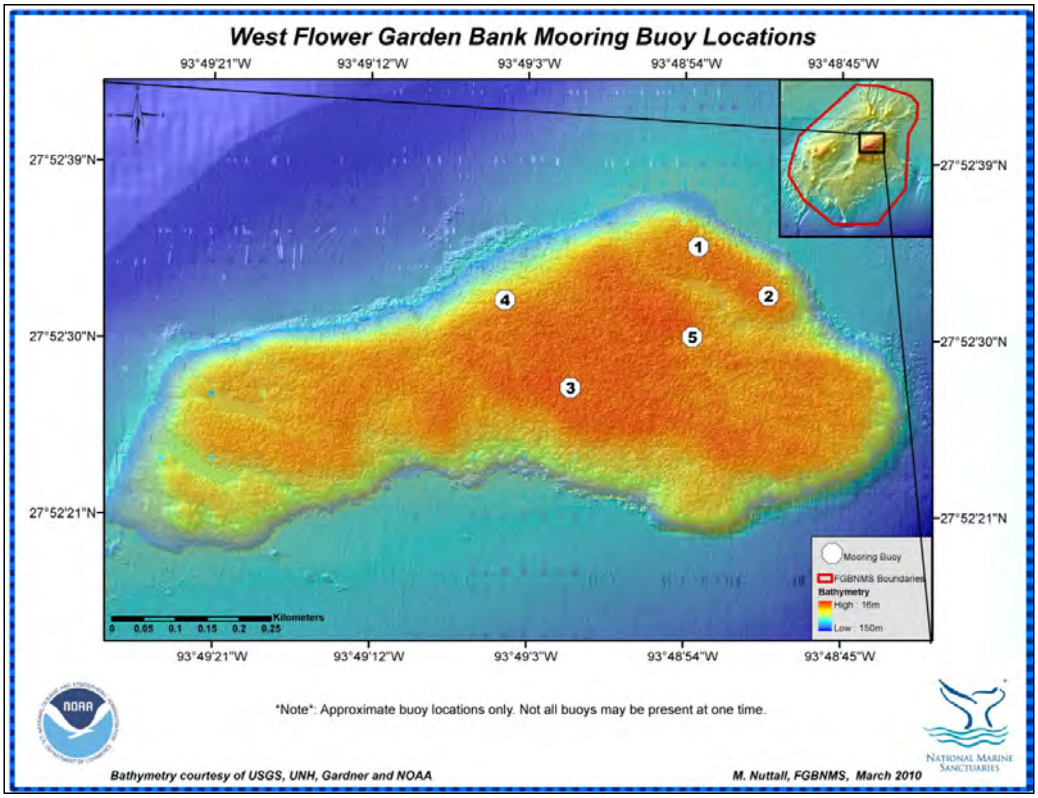


Figure 2.1.4. Locations of WFGB mooring buoys (NOAA/FGBNMS).

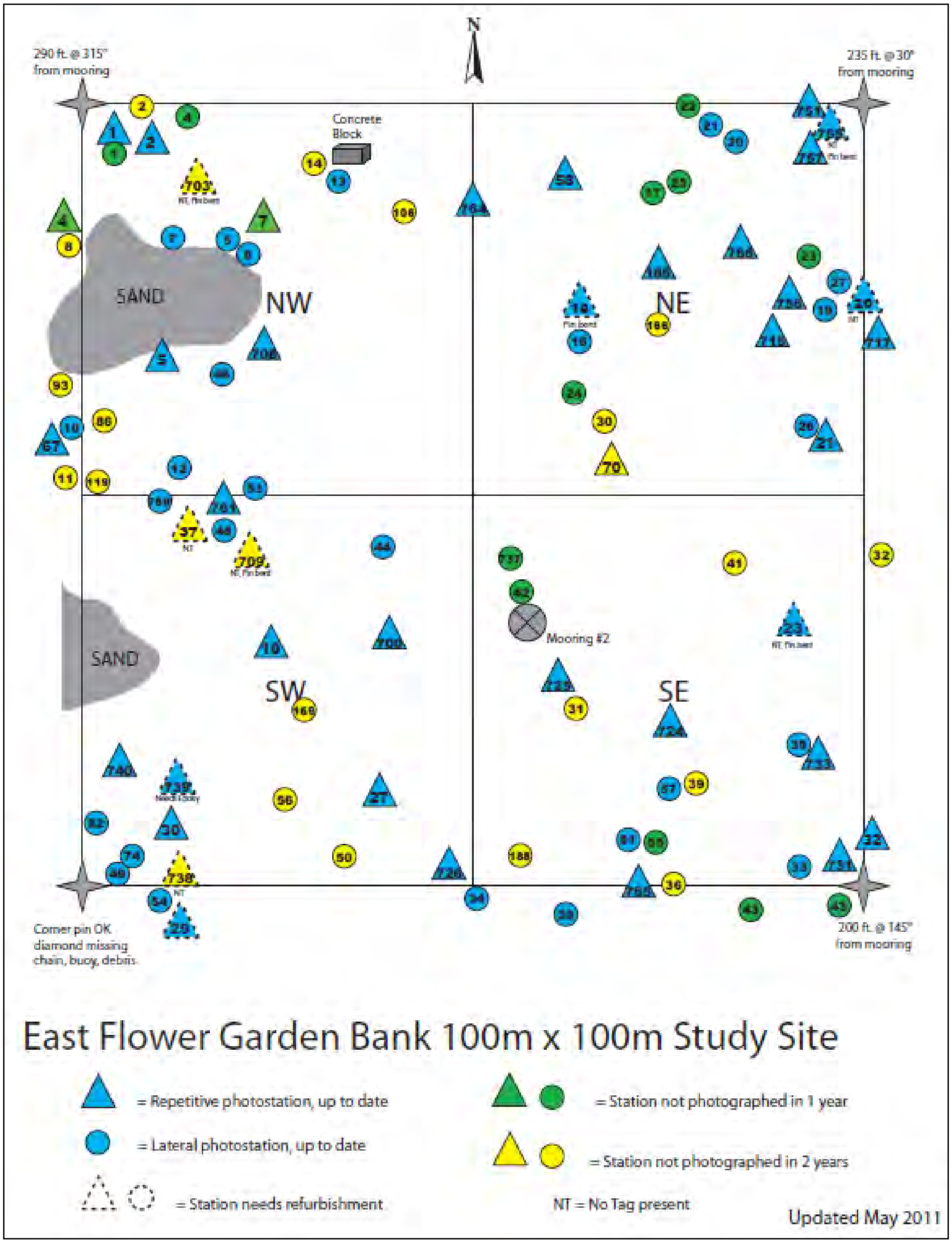


Figure 2.1.5. Locations of monitoring stations at the EFGB, 2010 (NOAA/FGBNMS).

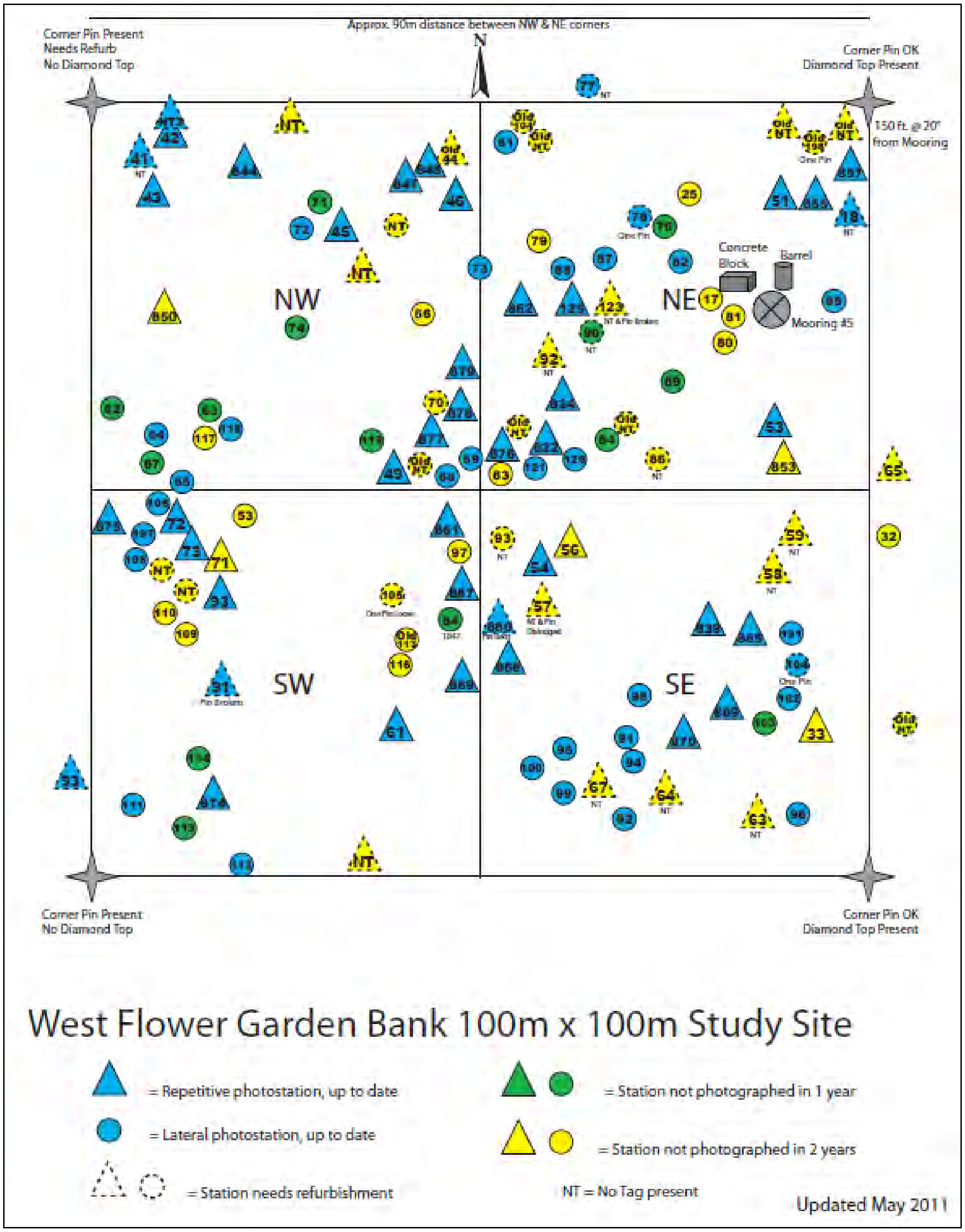
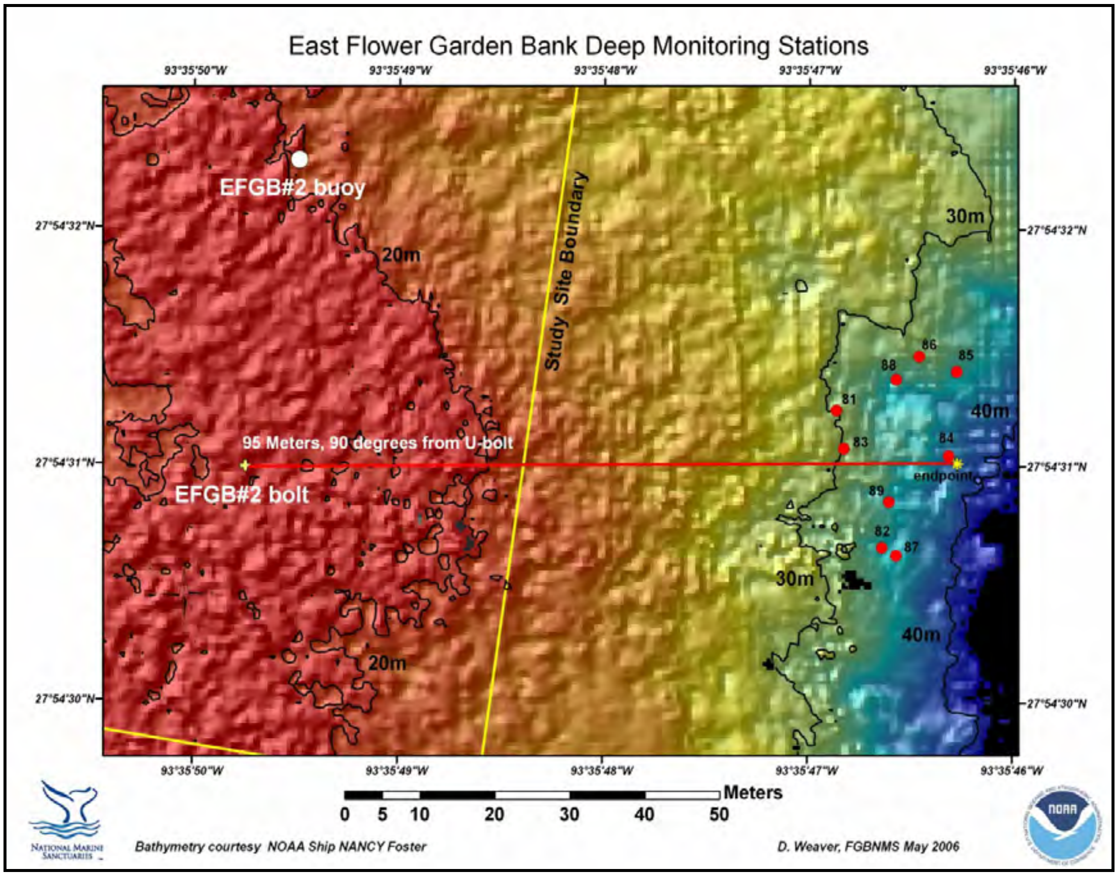


Figure 2.1.6. Locations of monitoring stations at the WFGB, 2010 (NOAA/FGBNMS).

2.1.2. EFGB Deep Repetitive Quadrat Stations

Nine deep repetitive quadrat stations are located outside the 100 x 100 m study site at the EFGB. These deep stations were established in April 2003 by BOEM and NOAA FGBNMS staff for comparision with the shallower repetitive photostations already in place (Precht et al. 2005). The stations were located east of the EFGB study site at depths between 32 m and 40 m (105 ft and 131 ft) (Figures 2.1.7 and 2.1.8; Precht et al. 2005).



Bathymetry courtesy NOAA Ship NANCY Foster

D. Weaver, FGBNMS May 2006

Note that the southern EFGB#2 u-bolt, formerly used as a mooring site, is no longer used; however, it is still marked and used as a point of reference. Contour lines at 20, 30, and 40 m (NOAA/FGBNMS).

Figure 2.1.7. Bathymetric map with the deep repetitive quadrat stations in relation to the permanent study site at the EFGB (32–40 m or 105–131 ft), established in April 2003.

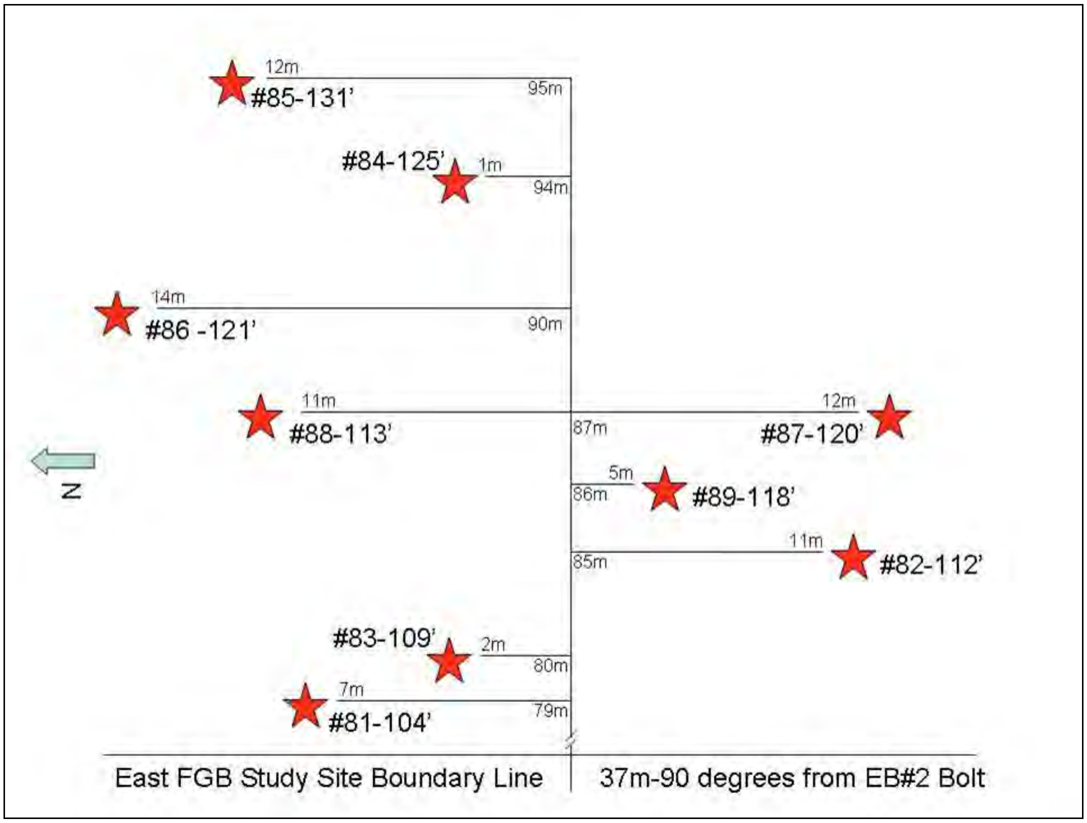


Figure 2.1.8. Map showing depth and relative locations of the nine deep repetitive quadrat stations at the EFGB.

2.1.3. Study Site Rehabilitation

In August 2009 and 2010, the monitoring team conducted site rehabilitation at the EFGB and WFGB study site. This was necessary to replace bent or missing rods at the lateral growth and repetitive quadrat stations, missing station photo tags, reinstall loose rods with epoxy, and install missing corner markers. Photostation tags were replaced on ten stations in 2009 and six stations in 2010. Maps depicting the locations of monitoring stations at the EFGB and WFGB were updated with new data, including station numbers, locations, replacements, and revisions for the study sites after each monitoring period. These revisions are reflected in the current site maps (Figures 2.1.5 and 2.1.6).

CHAPTER 3.0: RANDOM TRANSECTS

3.1. RANDOM TRANSECT METHODOLOGICAL RATIONALE

To estimate the areal coverage of benthic components such as corals, sponges, and macroalgae, 10 m (33 ft) fiberglass transect tapes were positioned randomly within each study site. Each transect originated at a random location using a randomly generated point on the perimeter boundary, followed by a randomly generated kick cycle distance, then laid out in a random direction according to a set of randomly generated numbers. Formerly conducted using still photography, the random transect methodology was changed to videography by principal investigators during the previous long-term monitoring contract period. Initial comparisons between still and video images were made in 2002 and 2003. Videography was then used in 2004 through 2008. It was used for the random transects by FGBNMS in 2009, but a decision was made to fully transition to digital still photography in 2010 due to the higher level resolution of the photographs (versus still images captured from video).

3.2. RANDOM TRANSECT FIELD AND LABORATORY METHODS

The desired design was four transects laid randomly within each quadrant of each study site, for a total of 16 transects. Although only 14 transects are required by the BOEM long-term monitoring Scope of Work (SOW), the research team strives to complete 16 transects every year. In some cases, however, only 14 transects were photographed. For each quadrant, a random number was generated between 0 and 50 to indicate the starting location along the first boundary line encountered (e.g., if the random number is 27 and the corner of the transect tape is 0, the transect is started at 27 m along the transect tape, and if the lowest corner of the transect tape is 50, the transect is started at 77 m along the transect tape). A second random number was generated between 0 and 40 to determine the number of fin kicks perpendicular from the boundary line into the study site. It is assumed that it takes 40 fin kicks to swim 50 m, assuming no opposing current. This randomly generated number of kicks provides the start location for the first transect. A randomly generated number between 0 and 360 was generated for the direction of the 10 m transect from the starting point, and a measuring tape was laid down to mark the transect.

The subsequent survey starting point was determined with a second set of randomly generated numbers. First, the number of fin kicks, between 12 and 40, was determined to ensure the starting point was at least 15 m away from the previous location. Second, the compass heading, between 1 and 360°, was established for the direction of the next 10 m transect. If a quadrant boundary was encountered, the line was reflected at a 90° angle back into the quadrant.

In 2009, a Sony PC1000 3 CCD digital video camera with L&M Housing and HID lights was used to collect digital videography. A diver swam slowly along each transect, videotaping at a height of 0.4 m (1.31 ft) off the seafloor (Aronson et al. 1994; Murdoch and Aronson 1999). The videographer maintained an approximate 0.4 m distance above the benthos using a weighted line attached to the video housing. The camera was aimed downward at a 90° angle to record the substratum.

The video frames covered a 40 cm (15.75 in) wide swath along each of the 10 m (33 ft) transects, for a total area of 4 m^2 (43 ft^2) per transect, or a minimum of approximately 56 m^2 (600 ft^2) videotaped per study site per year. Each video frame was approximately 40 x 27 cm (16 x 11 in) or 1080 cm^2 (167 in^2). Non-overlapping video frames were captured from each of the 16 video transects using Apple Final Cut Pro®. The original transect videotapes were used to gain more detail on objects or different perspectives on specific still images. Substrate cover was assessed from all captured images, as described below.

In 2010, a Canon Power Shot G11 digital camera was used in an Ikelite housing with a 28 mm equivalent wet mount lens adaptor to replace the video method. A diver mounted the camera on an aluminum t-frame, which allowed the camera lens to be 0.65 m above the substratum (Figure 3.2.1). The camera was placed at intervals marked on the tape at 55.88 cm (22 in) apart producing 19 non-overlapping images along the 10 m transect.

Each still frame image captured an 80 x 55 cm (31.45 x 21.65 in) area. This produced a total photographed area of 8.36 m^2 (89.99 ft^2) per transect, or a minimum of 117.04 m^2 (1259.81 ft^2) photographed per study site per year. The area captured using the digital still images increased from previous years to conform to image size requirements stated in the SOW.

Coral cover in the still frame images was analyzed using Coral Point Count with Microsoft® Excel® extensions (CPCe). CPCe is Windows®-based software that provides a tool for the determination of coral cover using transect photographs (Kohler and Gill 2006). A specified number of spatially random points are distributed on a quadrat image, and benthic species lying under these points are identified. Microsoft® Excel® spreadsheets can be created automatically to further analyze the data, and users can create their own customized code files pertinent to the cover of coral and other benthic species in their region of interest. CPCe is provided by the National Coral Reef Institute as freeware to researchers from scientific institutions and government agencies.

Randomly placed dots were added to each frame using CPCe, for a total of at least 500 dots per transect (Kohler and Gill 2006). The number of images obtained from each transect was divided by 500, and rounded up if necessary, to obtain the number of random points per photo in that transect. Organisms positioned beneath each random dot were identified as follows: corals, sponges, and macroalgae were identified to lowest possible taxonomic group (macroalgae included algae longer than approximately 3 mm and included thick algal turfs); and crustose coralline algae, fine turfs, and bare rock were grouped as "CTB." The components of the CTB group were combined for analysis not because they are difficult to distinguish (they are easy to tell apart), but because they are habitat where settlement of coral or sponges could occur. Macroalgae is not included in this category since settlement has already occurred. The CTB grouping was originally used by Aronson and Precht (2000) to characterize reefs in the Caribbean. The "other" categories included other live components (ascidians, fish, serpulids, etc.), sand, rubble, and unknown. The coverages of coral bleaching, paling, concentrated and isolated fish biting, and disease were also determined from random transects.

After each image was analyzed, the data were entered into project-specific Microsoft® Excel® spreadsheets. Quality assurance/quality control (QA/QC) for the video and photographic methods consisted of multiple, trained scientific divers diving together on the study sites and identifying corals and other taxa. Statistical comparisons of identifications by person (no statistically significant differences) were conducted to confirm the same identifications in the videos and photographs to ensure that they agreed on species identifications within the frames.

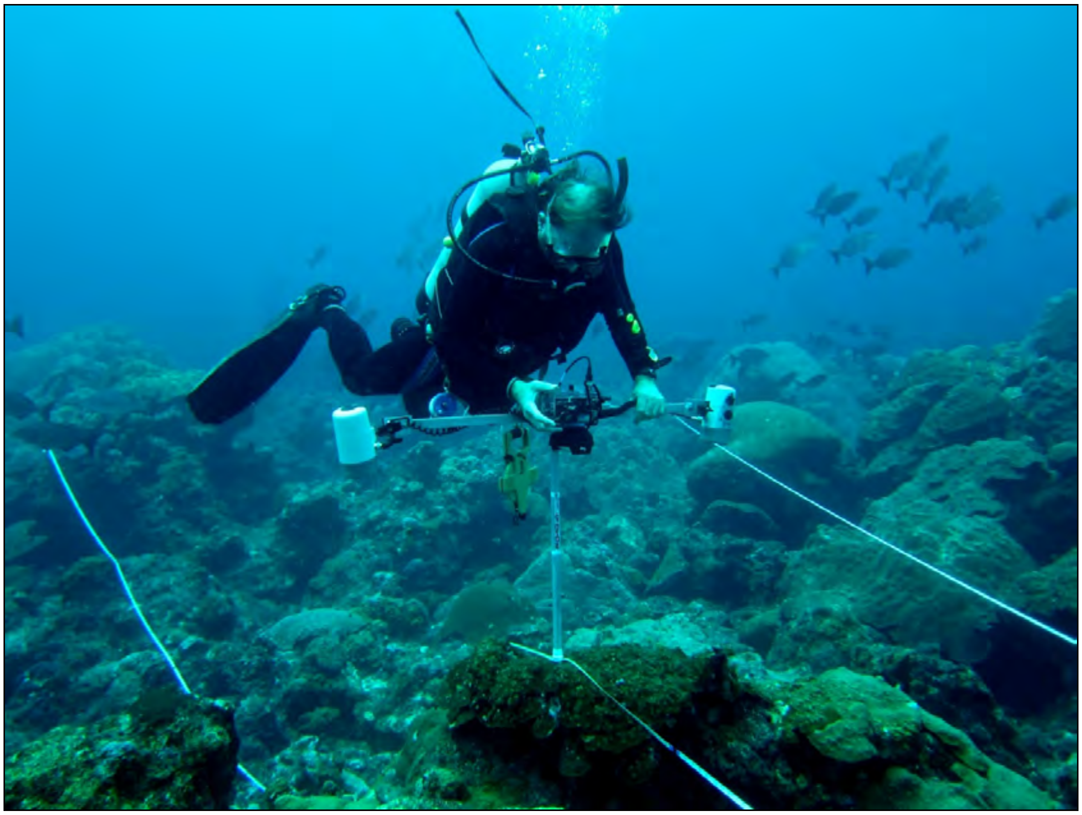


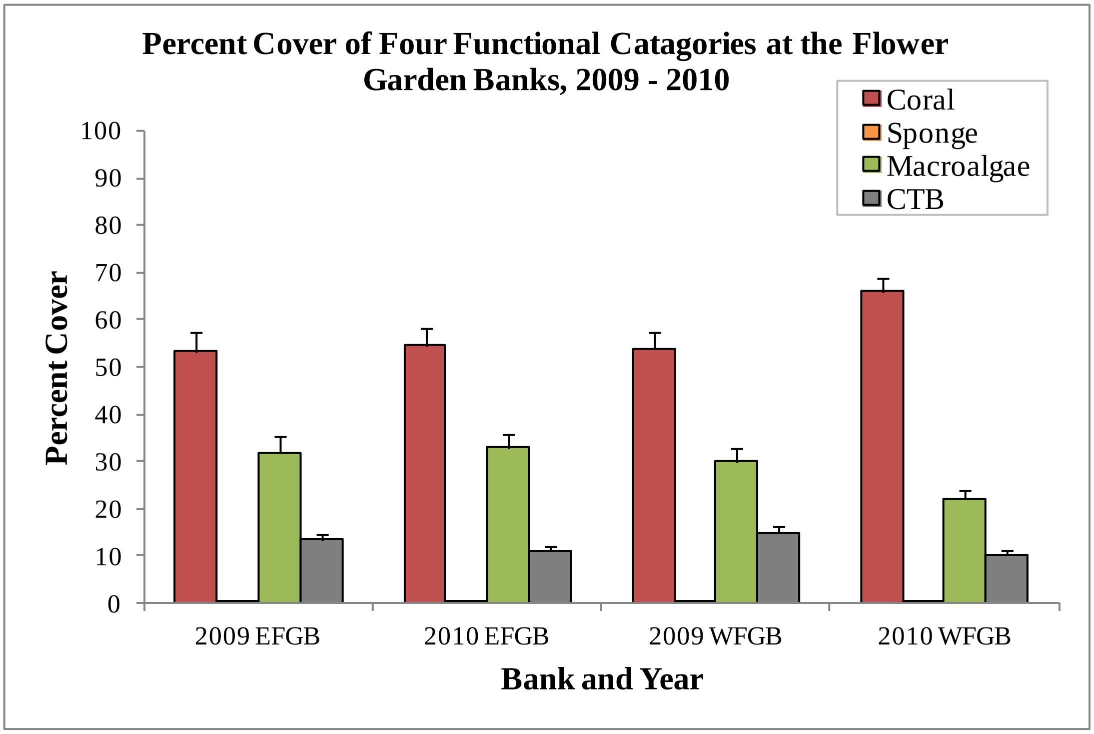
Figure 3.2.1. A diver with camera mounted on aluminum t-frame taking random transect photographs. The line to the diver's left is a study site boundary line (NOAA/FGBNMS).

3.3. STATISTICAL ANALYSES OF THE RANDOM TRANSECT DATA

Percent coverage was calculated for each transect from the 500 analyzed points for each of the taxa and benthic categories discussed in section 3.2. Factor plots were produced in CPCe to compare the average percent cover of major substrate types and coral species between reefs and through time. Previous examination of means and variances, using different numbers of random dots, suggested that 500 dots per transect provided required accuracy and precision for estimates of the coverage of benthic components, regardless of the transect length (Zimmer et al. 2010). Two-way Analyses of Variance (ANOVAs) were performed to test the null hypotheses that the response variables of interest did not differ between banks or among years. ANOVAs were calculated for each substratum variable with the statistical software JMP version 9.0.

3.4. RANDOM TRANSECT RESULTS

The point counts from the random transects were grouped into four major functional categories (coral, sponge, macroalgae, and CTB) and expressed as percent cover ± standard error. In general, random transect results from 2009 and 2010 revealed high coral cover, followed by macroalgae cover (thick turfs and fleshy macroalgal species) and relatively low levels of CTB (crustose coralline algae, fine turf algae, and bare rock). The sponge cover was very low as not many macrosponges are found at the FGB; however, encrusting sponges are common but do not show up in photographs because they are generally found on the underside of boulders. High levels of coral cover were consistent with past monitoring results, however, levels of macroalgae increased from previous monitoring periods, while levels of CTB decreased (Figure 3.4.1).



CTB: crustose coralline algae, fine turf algae, and bare rock. The “macroalgae” category includes thick turfs as well as fleshy macroalgal species. Values are calculated from the random transect photographs.

Figure 3.4.1. Percent cover (error bars are ± SE) of four functional categories of sessile benthos at the FGB from 2009 and 2010.

At the EFGB, coral cover remained stable from 2009 to 2010 (53.35% ± 4.17 to 54.49% ± 3.69), and the sponge cover remained extremely low for both years (0.13% ± 0.05 to 0.25% ± 0.13) (Figure 3.4.2 and Table 3.4.1). Macroalgae cover (mainly fleshy algae, turfs, and *Dictyota spp*.) remained stable from 2009 to 2010 (31.85% ± 3.49 to 32.94% ± 3.05), as did CTB cover (13.32% ± 1.07 to 11.15% ± 0.86). Consistent with past monitoring results, the *Montastraea annularis* species complex (MASC), containing *M. annularis*, *M. faveolata*, and *M. franksi*, continued to dominate the EFGB in 2009 (29.52% ± 12.99) and 2010 (38.89% ± 3.84). *Diploria strigosa* (10.08% ± 2.54 and 9.38% ± 1.72 in 2009 and 2010, respectively) and *Porites astreoides* (4.93% ± 1.29 in 2009 and 5.11% ± 0.69 in 2010) were the next most abundant species (Figure 3.4.2 and Table 3.4.1). The remaining coral cover was made up of eleven species, none of which exceeded 4.0% individually in either 2009 or 2010 (Table 3.1.1). Shannon-Weiner diversity values remained consistent at the EFGB (H'=0.97 and H'=0.95 in 2009 and 2010, respectively).

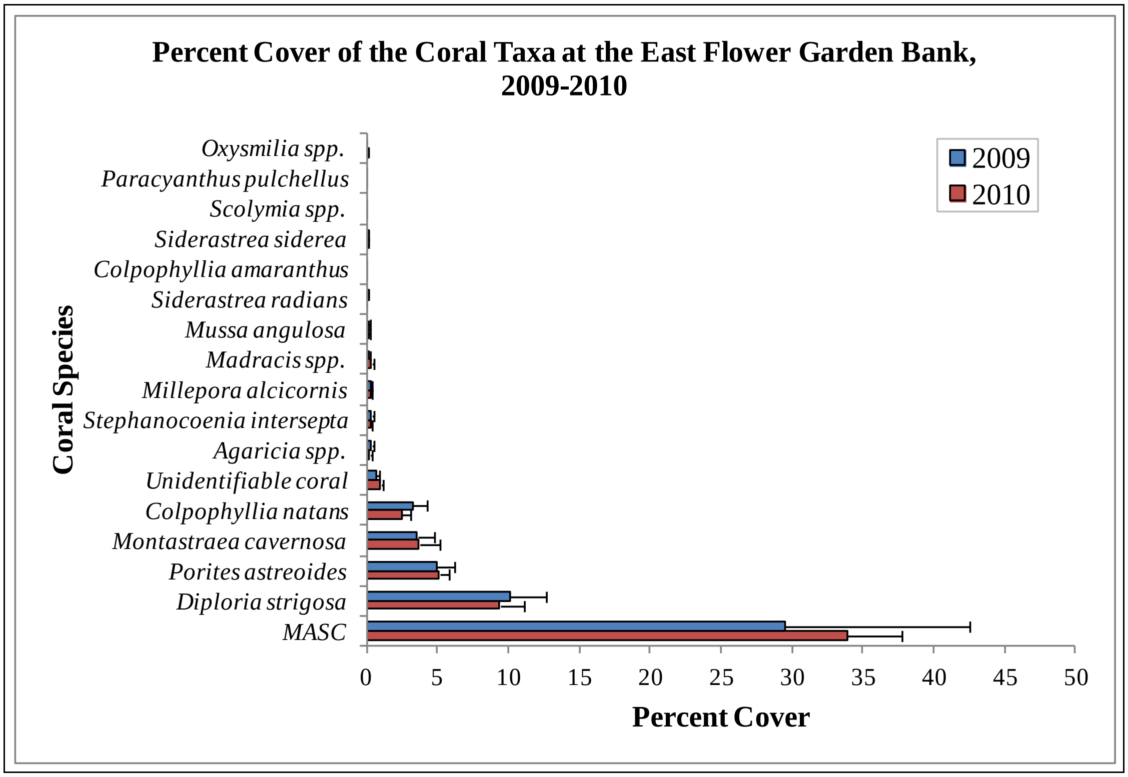
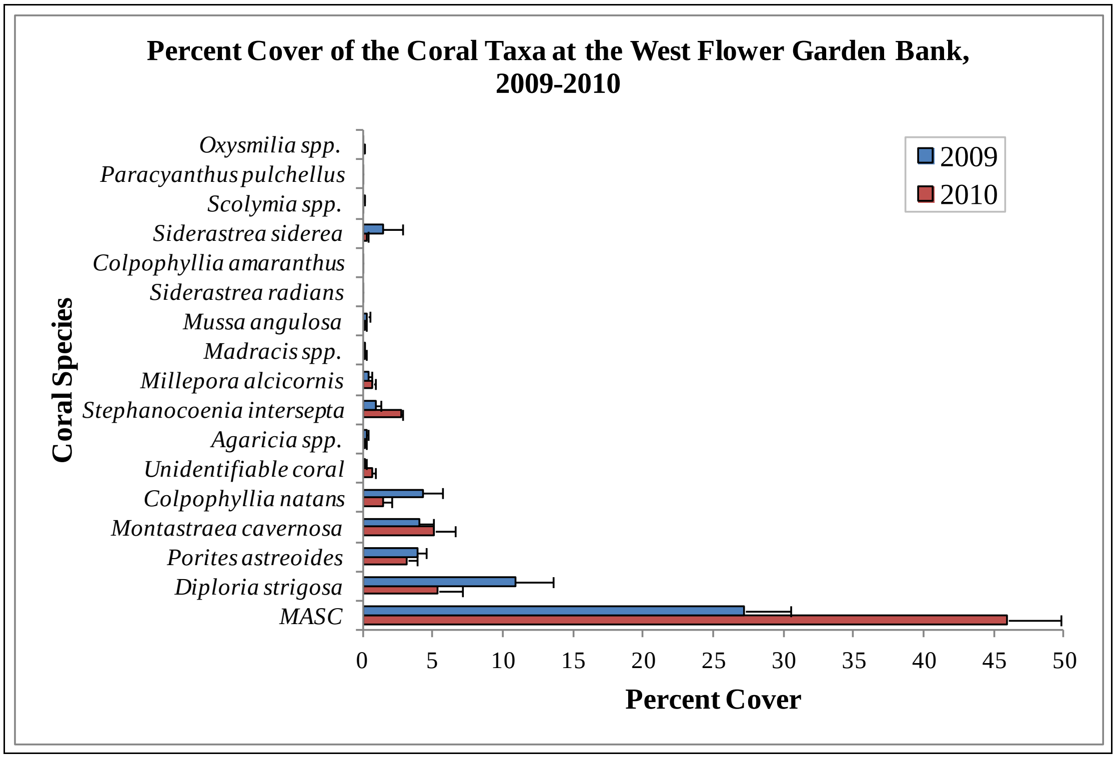


Figure 3.4.2. Percent cover (+ SE) of the dominant coral taxa at the EFGB from 2009 and 2010. Values are calculated from the random transect photographs.

At the WFGB, the 2009 coral cover remained consistent with previous years (53.84% ± 3.73); however, coral cover was higher in 2010 (65.95% ± 2.85). The sponge cover remained extremely low for both years at the WFGB (0.10% ± 0.05 to 0.25% ± 0.10) (Figure 3.4.3 and Table 3.4.1). Macroalgae cover decreased from 2009 to 2010 (30.03% ± 2.63 to 22.03% ± 2.00), while CTB cover remained relatively stable (14.93% ± 1.52 to 10.20% ± 1.03). As with the EFGB, the *Montastraea annularis* species complex continued to dominate the WFGB in 2009 (27.25% ± 3.32) and 2010 (45.98% ± 3.68). *Diploria strigosa* (10.84% ± 2.70 and 5.39% ± 0.94 in 2009 and 2010, respectively) and *Porites astreoides* (3.85% ± 0.64 in 2009 and 3.20% ± 0.62 in 2010) were the next most abundant species (Figure 3.4.3 and Table 3.4.1). The remaining coral cover was made up of eleven species, none of which exceeded 6.0% individually in either 2009 or

2010 (Table 3.1.1). Shannon-Weiner diversity values were higher at the WFGB in 2009 than in 2010 (H’=0.98 and H’=0.88 in 2009 and 2010, respectively).



Values are calculated from the random transect photographs.

Figure 3.4.3. Percent cover (+ SE) of the dominant coral taxa at the WFGB from 2009 and 2010.

Table 3.4.1.

Cover of Benthic Categories in Random Transects at the EFGB and WFGB from 2009 and 2010

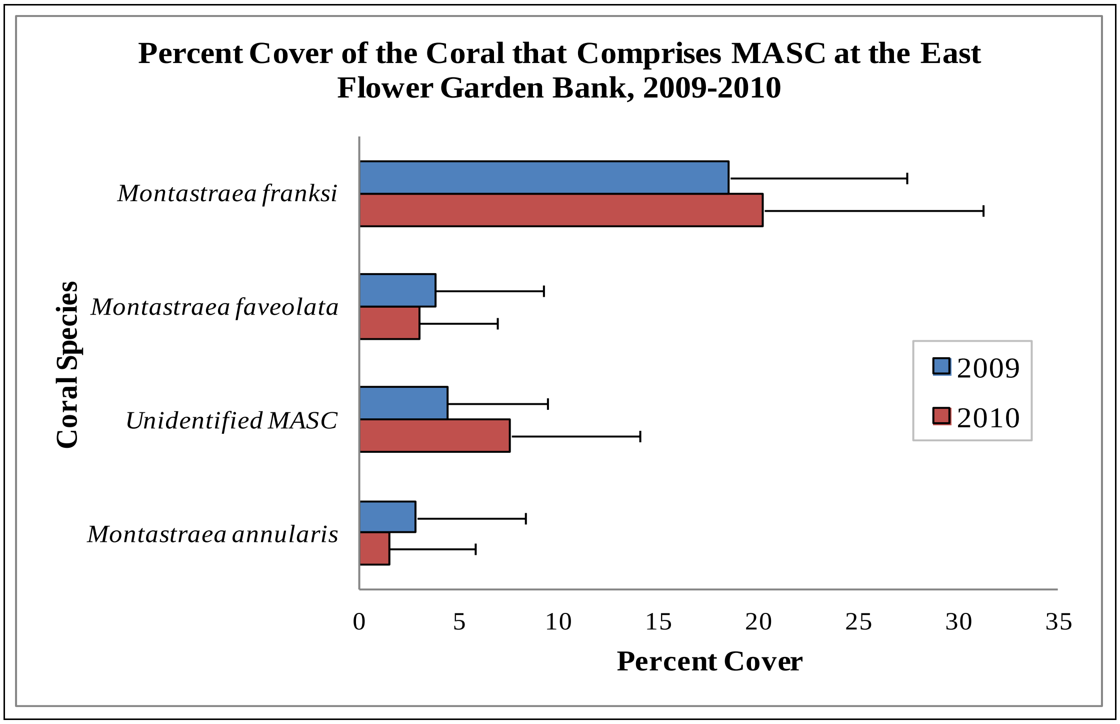
Values are expressed as percent cover ± SE.

Cover Category	**2009 EFGB**	**2010 EFGB**	**2009 WFGB**	**2010 WFGB**
Coral				
Montastraea annularis species complex	29.52 ± 12.99	33.89 ± 3.84	27.25 ± 3.32	45.98 ± 3.68
Diploria strigosa	10.08 ± 2.54	9.38 ± 1.72	10.84 ± 2.70	5.39 ± 0.94
Porites astreoides	4.93 ± 1.29	5.11 ± 0.69	3.85 ± 0.64	3.20 ± 0.62
Montastraea cavernosa	3.58 ± 1.22	3.71 ± 1.46	4.03 ± 0.97	5.09 ± 1.12
Colpophyllia natans	3.21 ± 1.00	2.45 ± 0.63	4.26 ± 1.38	1.45 ± 0.42
Unidentifiable coral	0.65 ± 0.25	0.96 ± 0.20	0.19 ± 0.07	0.62 ± 0.23
Agaricia spp.	0.34 ± 0.17	0.21 ± 0.08	0.24 ± 0.07	0.18 ± 0.08
Stephanocoenia intersepta	0.30 ± 0.13	0.27 ± 0.12	0.94 ± 0.27	2.74 ± 2.03
Millepora alcicornis	0.25 ± 0.15	0.24 ± 0.10	0.41 ± 0.16	0.73 ± 0.32
Madracis spp.	0.22 ± 0.07	0.31 ± 0.17	0.05 ± 0.04	0.06 ± 0.03
Mussa angulosa	0.10 ± 0.07	0.12 ± 0.06	0.32 ± 0.14	0.13 ± 0.07
Siderastrea radians	0.09 ± 0.06	0.00	0.00	0.00
Colpophyllia amaranthus	0.00	0.00	0.00	0.00
Siderastrea siderea	0.03 ± 0.02	0.10 ± 0.06	1.44 ± 1.33	0.33 ± 0.31
Scolymia spp.	0.00	0.00	0.02 ± 0.02	0.00
Paracyanthus pulchellus	0.00	0.00	0.00	0.00
Oxysmilia spp.	0.00	0.01 ± 0.01	0.00	0.04 ± 0.02
Total Coral	**53.35 ± 4.17**	**54.49 ± 3.69**	**53.84 ± 3.73**	**65.95 ± 2.85**
Sponge				
Agelas clathrodes	0.03 ± 0.02	0.09 ± 0.06	0.06 ± 0.05	0.01 ± 0.01
Arolochroia (Pseudoceratina) crassa	0.01 ± 0.01	0.05 ± 0.05	0.01 ± 0.01	0.06 ± 0.06
Ectyoplasia ferox	0.00	0.03 ± 0.03	0.00	0.03 ± 0.02
Ircinia strobilina	0.03 ± 0.03	0.00	0.00	0.00
Mycale laxissima	0.00	0.00	0.00	0.01 ± 0.01
Neofibularia nolitangere	0.03 ± 0.03	0.00	0.03 ± 0.03	0.00
Unidentifiable Sponge	0.01 ± 0.01	0.07 ± 0.07	0.00	0.07 ± 0.06
Xestospongia muta	0.01 ± 0.01	0.01 ± 0.01	0.00	0.04 ± 0.03
Encrusting sponge	0.24 ± 0.11	0.28 ± 0.13	0.26 ± 0.06	0.16 ± 0.06
Spirastrelle cunctatrix	0.00	0.07 ± 0.04	0.01 ± 0.01	0.11 ± 0.06
Unidentifiable Encrusting Sponge	0.00	0.03 ± 0.03	0.00	0.00
Total Sponge	**0.13 ± 0.05**	**0.25 ± 0.13**	**0.10 ± 0.05**	**0.25 ± 0.10**
CTB				

Cover Category	**2009 EFGB**	**2010 EFGB**	**2009 WFGB**	**2010 WFGB**
Bare Substrate	6.13 ± 1.02	6.73 ± 0.77	7.34 ± 0.98	4.83 ± 0.78
Crustose Coralline Algae	2.55 ± 0.41	3.06 ± 0.38	1.46 ± 0.41	3.21 ± 0.49
Fine Turf	4.64 ± 0.42	1.36 ± 0.24	6.14 ± 0.61	2.16 ± 0.35
Total CTB	**13.32 ± 1.07**	**11.15 ± 0.86**	**14.93 ± 1.52**	**10.20 ± 1.03**
Macroalgae				
Fleshy algae	13.53 ± 2.27	17.64 ± 2.18	19.74 ± 2.03	9.18 ± 1.00
Thick turf algae	11.85 ± 1.48	1.44 ± 0.35	6.65 ± 1.28	0.70 ± 0.29
Dictyota spp.	6.00 ± 1.05	9.95 ± 1.74	1.04 ± 0.25	1.62 ± 0.56
Lobophora variegata	0.48 ± 0.11	3.89 ± 0.56	2.60 ± 0.36	10.53 ± 2.08
Filamentous Algae	0.00	0.01 ± 0.01	0.00	0.00
Total Macroalgae	**31.85 ± 3.49**	**32.94 ± 3.05**	**30.03 ± 2.63**	**22.03 ± 2.00**
Other				
Shadow	5.96 ± 0.65	6.66 ± 0.69	6.27 ± 1.12	7.43 ± 1.02
Sand	0.57 ± 0.33	0.21 ± 0.12	0.57 ± 0.25	0.58 ± 0.18
Substrate Rubble	0.21 ± 0.17	0.31 ± 0.20	0.12 ± 0.05	0.43 ± 0.15
Fish	0.04 ± 0.02	0.03 ± 0.02	0.01 ± 0.01	0.00
Invertebrate	0.28 ± 0.05	0.20 ± 0.06	0.11 ± 0.04	0.29 ± 0.06
Coral Condition (occurences in coral)				
Bleached Coral	0.14 ± 0.10	0.02 ± 0.02	0.16 ± 0.13	6.98 ± 2.06
Paling Coral	0.76 ± 0.46	0.36 ± 0.12	0.39 ± 0.21	11.09 ± 3.33
Concentrated Fish Biting	0.00	0.05 ± 0.05	0.09 ± 0.05	0.02 ± 0.02
Isolated Fish Biting	0.03 ± 0.03	0.00	0.06 ± 0.06	0.02 ± 0.02

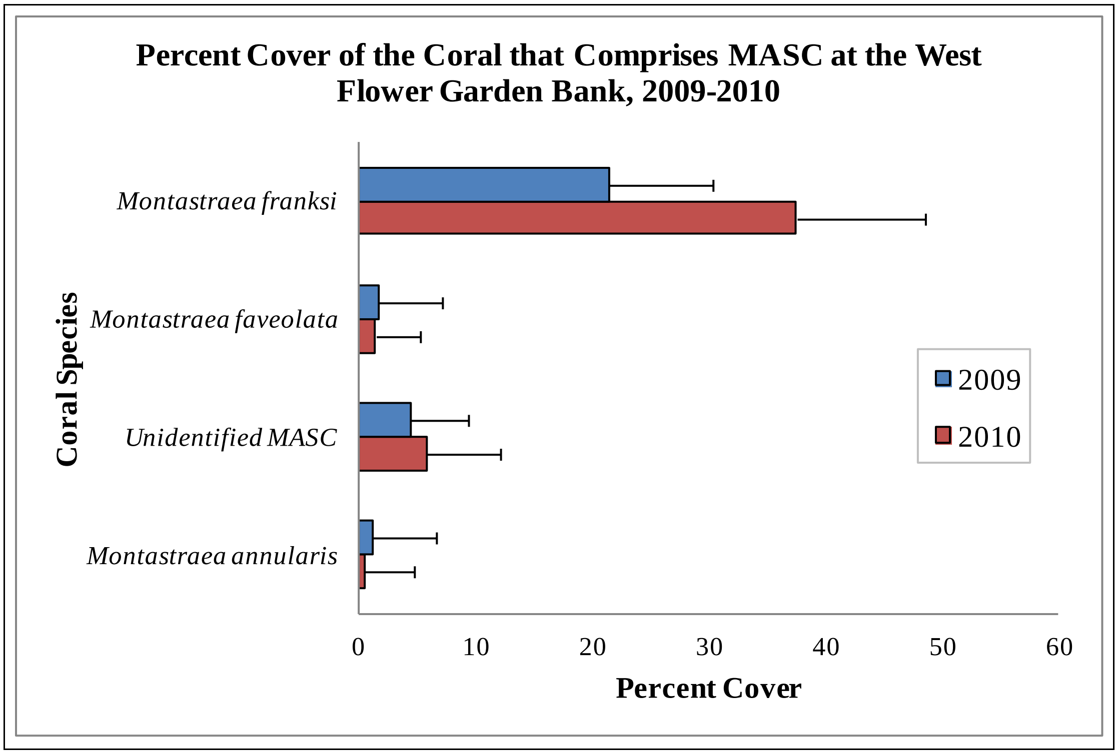
The combined data collected from 2009 and 2010 showed persistence of the *Montastraea annularis* species complex as the dominant coral species at the EFGB and WFGB (Table 3.4.1). Likewise, *Diploria strigosa* remained the second-most prevalent coral species during this time period. *Porites astreoides* and *M. cavernosa* were consistently the third and fourth most dominant corals at the EFG, while *M. cavernosa* was the third dominant and *Porites astreoides* was the fourth dominant coral at WFGB. The average coral cover between the EFGB and WFGB determined by random transect data was 56.95% for the 2009 and 2010 reporting period. Appendix 1 in Volume II of this report contains the random transect data from 2009 and 2010 at the FGB.

In past monitoring years, the *Montastraea annularis* species complex (*M. annularis*, *M. faveolata*, and *M. franksi*) has been difficult to differentiate using the photographic and videographic techniques employed in this study (primarily because the scale of the photograph does not allow visualization of the entire colony formation, which can be very helpful for identification). However, with improved digital photography resolution and the familiarity of the FGBNMS staff with the photostations, the components of the *Montastraea annularis* species complex were individually indentified. At the EFGB and WFGB, the *Montastraea annularis* species complex is dominated by *M. franksi*, followed by *M. faveolata* and *M. annularis*. At the EFGB, *M. franksi* percent cover remained stable from 2009 to 2010 (18.50% ± 8.90 to 20.20% ± 11.00), and *M. faveolata* (3.80% ± 5.42 to 3.00% ± 3.92) and *M. annularis* (2.84% ± 5.42 to 1.47% ± 4.34) remained stable as well (Figure 3.4.4). At the WFGB, *M. franksi* percent cover of the MASC was significantly higher in 2010 (21.44% ± 9.81 in 2009 and 37.54% ± 12.98 in 2010), while *M. faveolata* (1.65% ± 2.62 to 1.40% ± 4.09) and *M. annularis* (1.18% ± 3.88 to 0.48% ± 1.73) remained stable (Figure 3.4.5). Approximately 5.5% of the MASC components were unable to be differentiated, which may be due to MASC hybridization or genotypic variation.



Values are calculated from the random transect photographs.

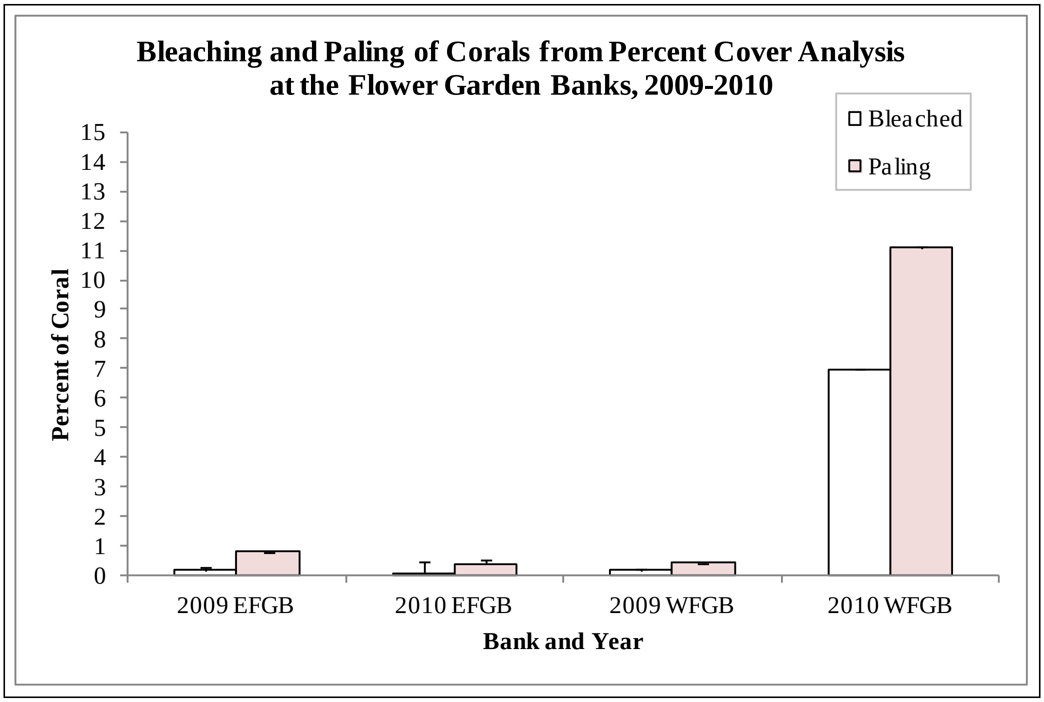
Figure 3.4.4. Percent cover (+ SE) of the coral species that comprise the MASC at the EFGB from 2009 and 2010 (note scale difference from Figure 3.4.5).



Values are calculated from the random transect photographs.

Figure 3.4.5. Percent cover (+ SE) of the coral species that comprises the MASC at the WFGB from 2009 and 2010 (note scale difference from Figure 3.4.4).

In the 2009 and 2010 random transects, the incidences of bleaching, paling, and fish biting were low at both banks and coral disease was absent (Table 3.4.1). The percentage of corals impacted by isolated/concentrated fish biting at the EFGB and WFGB was minimal, ranging from 0.00 to 0.09%. Less than 1% of the coral cover analyzed in the random transects was diseased or bleached at the EFGB in 2009 and 2010 and at the WFGB in 2009; however, higher incidences of bleaching (~7%) and paling (~11%) were observed at the WFGB in 2010 (Figure 3.4.6).



Values are calculated from coral cover in the random transect photographs.

Figure 3.4.6. Percent of coral observed to pale and bleach (+ SE) at the FGB in 2009 and 2010.

In 2009 and 2010, 58% of the bleached coral cover was in the *Montastraea annularis* species complex (Figure 3.4.7). Twenty-eight percent was *Montastraea cavernosa* (28%). Of the cover that was observed to pale, 74% was in the *Montastraea annularis* species complex, followed by 14% for *Montastraea cavernosa* (Figure 3.4.8). The elevated bleaching and paling levels at the WFGB in 2010 will be further discussed in the Discussion section of this report.

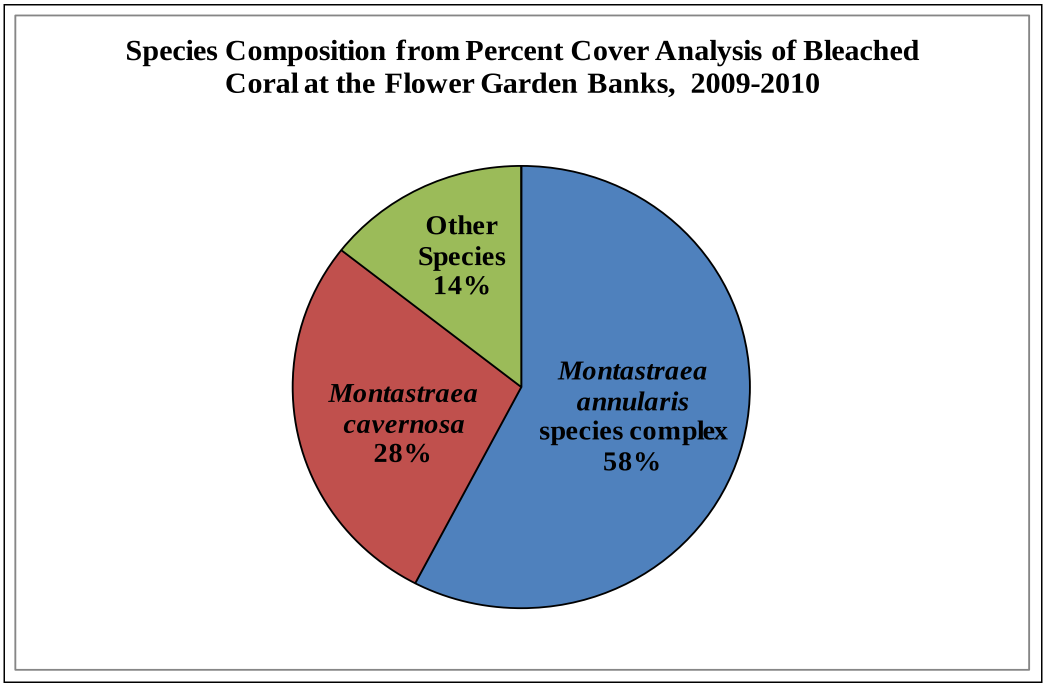


Figure 3.4.7. Species composition of bleached coral from percent cover random transect analysis at the FGB from 2009 and 2010.

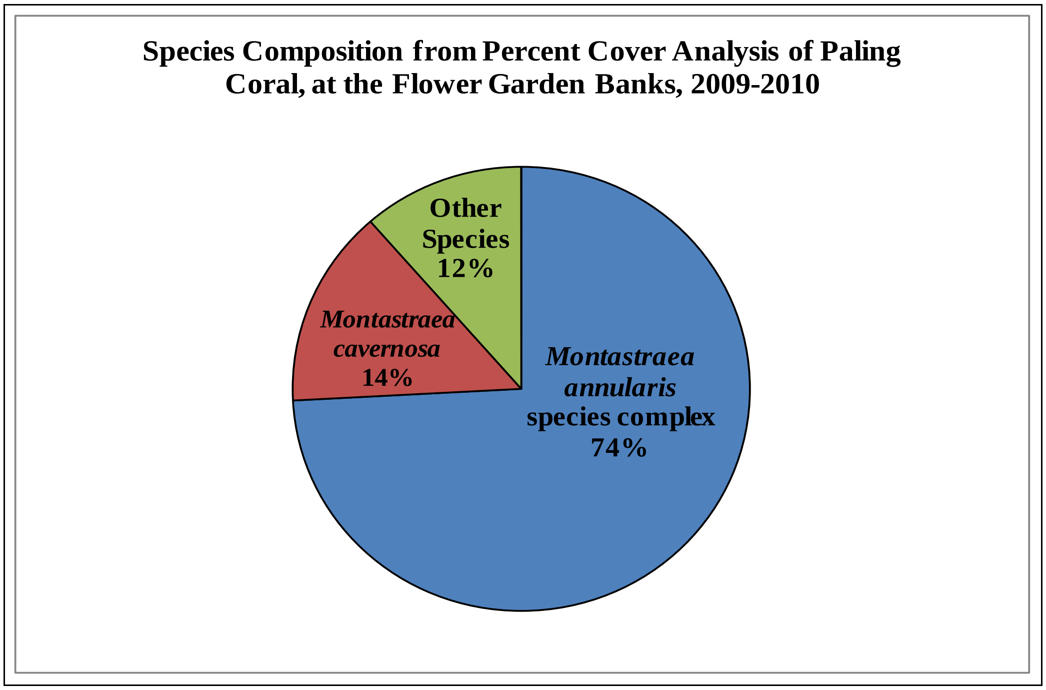


Figure 3.4.8. Species composition of paling coral from percent cover random transect analysis at the FGB from 2009 and 2010.

The point count data that were grouped into the four major functional categories (coral, sponge, macroalgae, and CTB) and expressed as percent covers were analyzed by two-way analysis of variance (ANOVA), with Site (EFGB and WFGB) and Year (2009 and 2010) as fixed factors. Prior to analysis, the data were tested for conformity to the parametric assumptions of normality and homogeneity of variances. All data were log transformed to assume a normal distribution.

A two-way ANOVA on the proportional cover of all living hard corals (Scleractinia and Milleporina) showed no significant effect of Site or Year, and the Site x Year interaction was also not significant (Table 3.4.2 A). A two-way ANOVA on the proportional cover of sponges showed no significant effects of Site or Year, and the Site x Year interaction was also not significant (Table 3.4.2 B).

A two-way ANOVA on the proportional cover of macroalgae showed no significant effects of Year, and the Site x Year interaction was also not significant, however, the effects of Site were significant (Table 3.4.2 C). Overall, macroalgal cover was higher at the EFGB than the WFGB during the study period. Because the effect of Site was significant, a simple one-way ANOVA was performed on the macroalgal data for each bank separately to examine Site variations. The data for the EFGB was significantly different from that of the WFGB (F=10.59, df=1, 62, P-value <0.0191). Tukey–Kramer *a posteriori* comparisons also showed that macroalgal cover was significantly higher at the EFGB than the WFGB.

A two-way ANOVA on the fourth cover category, CTB (crustose coralline algae, fine algal turfs and bare rock), showed no significant effects of Site, and the Site x Year interaction was also not significant, however, the effects of Year were significant (Table 3.4.2 D). Overall, CTB cover was lower at the EFGB in 2009, but higher at the WFGB in 2010. Because the effect of Year was significant, a simple one-way ANOVA was performed on the CTB data to examine year-to-year variations. The data for 2009 was significantly different 2010 (F=6.14, df=1, 62, P-value <0.0177). Tukey–Kramer *a posteriori* comparisons also showed that CTB cover was significantly higher in 2009 than in 2010.

Table 3.4.2.

Results of ANOVA on Proportional Cover Estimates from Random Transects from 2009 and 2010

Comparisons of groups where ANOVA was performed are in bold with appropriate P-values where significant.

(A) Hard Corals (log transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	**P-value**
Site	0.3308	1		2.18	0.15
Year	0.3866	1		2.55	0.12
Site*Year	0.0650	1	0.26	0.43	0.52
Error	8.9455	59	0.15		
Total	9.7267	62			
(B) Sponges (log transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	**P-value**
Site	0.0006	1		0.0109	0.9173
Year	0.0978	1		1.7403	0.1922
Site*Year	0.0044	1	0.0346	0.0786	0.7802
Error	3.3170	59	0.0562		
Total	3.4208	62			
(C) Macroalgae (log transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	**P-value**
Site	0.7389	1		5.8051	**0.0191**
Year	0.2823	1		2.2177	0.1418
Site*Year	0.4405	1	0.4925	3.4608	0.0678
Error	7.5096	59	0.1273		
Total	8.9870	62			
(D) CTB (log transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	**P-value**
Site	0.0082	1		0.0618	0.8046
Year	0.7937	1		5.9532	**0.0177**
Site*Year	0.0681	1	0.2920	0.5107	0.4776
Error	7.8657	59	0.1333		
Total	8.7418	62			

Finally, the Shannon-Wiener diversity index, H', was calculated from the species-specific coral cover data from each transect. The three species of the *Montastraea annularis* species complex were combined for the calculation. The Shannon-Wiener diversity index is used to give a measure of both species numbers and evenness (the apportionment of individuals among species), resulting in a biodiversity measure that is useful when comparing similar habitats. The Shannon-Wiener diversity values at the EFGB were H’= 0.97 in 2009 and H’=0.95 in 2010. The values at the WFGB were H’= 0.98 in 2009 and H’=0.88 in 2010. The low values of H' reflect the low diversity, yet high coral cover, particularly of the strong dominance of the *Montastraea annularis* species complex.

In summary, combined mean coral cover averaged approximately 56% at the EFGB and WFGB in the period 2009 through 2010. These values were consistent with measurements of coral cover above 50% at the FGB in previous years (Dokken et al. 2003; Precht et al. 2006) and they are high compared to other western Atlantic reefs (e.g., Aronson et al. 1994; Gardner et al. 2003). Macroalgae ranked second behind the corals, and sponge cover was extremely low. This pattern was consistent with recent results from the EFGB and WFGB (Aronson et al. 2005; Precht et al. 2006; Zimmer et al. 2010) and previous work in the Caribbean (Aronson and Precht 2000).

3.5. RANDOM TRANSECT DISCUSSION

In a global trend of declining coral reef health and cover, the FGB continues to support high coral cover compared to other reefs of the western Atlantic and Caribbean region (Aronson et al. 1994, 2005; Gardner et al. 2003; AGRRA 2003; Pina Amargós et al. 2008; ONMS 2011; Steneck et al. 2011) (Table 3.5.1). Gardner et al. (2003) reported the regional decline of corals across the Caribbean basin over the last three decades, with the average hard coral cover on reefs decreasing from approximately 50% to 10%. Natural and anthropogenic factors, including storm events, temperature stress, disease, predation, overfishing, sedimentation, eutrophication, and habitat destruction have all played a part in the decline (Aronson and Precht 2001; Rogers and Beets 2001; Gardner et al. 2003).

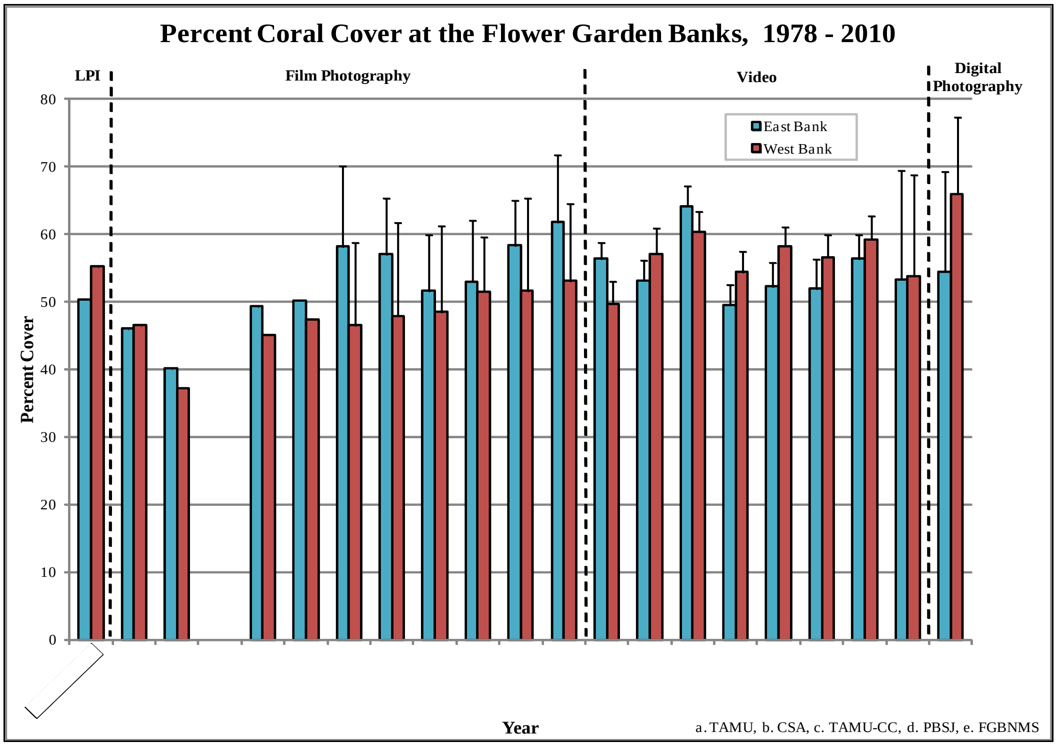
Table 3.5.1.

Percentage of Coral Cover on Living Reefs in the Western Atlantic and Caribbean Region

Location	Percent Coral Cover	Source
Flower Garden Banks NMS	56	this report
Netherlands Antilles	10–47	AGRRA 2003
St. Vincent Grenadines	29–44	AGRRA 2003
Bonaire	38	Steneck et al. 2011
Turks and Caicos	up to 30	AGRRA 2003
Florida Keys NMS	3–20	ONMS 2011
Cayman Islands	21	AGRRA 2003
Jardin de la Reina, Cuba	7–19	Pina Amargós et al. 2008
Akumal, Mexico	17	AGRRA 2003

Caribbean reefs that have historically displayed high coral cover are showing declines, mainly due to algae competition, bleaching and/or coral disease. Bonaire reported a decrease in coral cover from 38% to 10% in 2011 (Steneck et al. 2011), and the Florida Keys National Marine Sanctuary is maintaining approximately 7% coral coverage with ranges from about 3% to 20% (ONMS 2011). The Cuban reefs within Jardin de la Reina range from 7% to 9% cover (Pina Amargós et al. 2008). In contrast, coral cover at the FGB has remained relatively stable over time (Figure 3.5.1). Univariate analysis of the random transect data revealed that the average coral cover at the EFGB and WFGB remained high from 2009 to 2010 (56.95%). Coral cover was also similar to values from earlier studies, (Dokken et al. 1999, 2001; CSA 1996; Gittings et al. 1992), highlighting the stability of the coral assemblage over time (Figure 3.5.1).

Some reasons for the exceptional condition of the FGB include (1) water depth of the reefs, which buffers the reef cap from the effects of storm waves and variable seasurface temperatures; (2) the remote offshore location, which limits human access and exposes these reefs consistently to oligotrophic, oceanic waters; (3) healthy grazer populations; and (4) protective federal regulations, which prevent hydrocarbon-related effects, as well as effects from anchoring, fishing and recreational diving (Aronson et al. 2005). The importance of the FGB, in terms of the Atlantic coral reef system as a whole, has been substantially elevated because of the regional decline of corals. Consequently, it could be argued that the estimated loss value would be higher for the FGB in the event of a severe industrial accident, expansion of the zone of influence of the Mississippi River, or other significant change in environmental conditions.



No percent cover data were reported in 1993. Data for 1978 to 1982 from Gittings et al. (1992), who reported data from Kraemer (1982); for 1988 to 1991 from Gittings et al. (1992); for 1992 to 1995 from Continental Shelf Associates, Inc. (CSA) (1996); for 1996 to 2001 from Dokken et al. (2003); 2002 to 2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009 and 2010 (Johnston et al. 2012).

Figure 3.5.1. Random transect mean percent coral cover at the EFGB and WFGB over time, showing the consistently high coral cover.

3.5.1. EFGB Comparison from 2009 to 2010

The random transect data for the EFGB showed similar values for coral, sponge, CTB, macroalgae cover and H' in both years. The three dominant coral taxa—the *Montastraea annularis* species complex, *Diploria strigosa* and *Porites astreoides*—varied little from 2009 to 2010. The H' for the coral assemblage was low at the EFGB due to the low species-richness values and the dominance of a few species, namely the *M. annularis* species complex and *D. strigosa*. The most noticeable pattern was consistent coral cover at the EFGB compared to the other sampling years.

3.5.2. WFGB Comparison from 2009 to 2010

The random transect data for the WFGB showed similar values for sponge, CTB, macroalgae cover and H' in both years. However, coral cover was significantly higher at the WFGB in 2010 (65.95% ± 2.85) than in 2009 (53.84% ± 3.73). Much of the variation was likely due to the transect placement, rather than reflecting real variations. Past studies have documented similar variations in relative abundance from year to year and were often attributable to sampling or image analysis error (Dokken et al. 2003, 1999); however, photographs were analyzed multiple times in the CPCe software to ensure coral was identified correctly. It was determined that the randomness of the transect placements resulted in more areas containing high coral cover than in years past, resulting in an artifact from the 2010 sampling season. As with the EFGB, the three dominant coral taxa—the *Montastraea annularis* species complex, *Diploria strigosa* and *Porites astreoides*—fluctuated to a negligible degree. Overall, the most noticeable pattern was higher coral cover in 2010, when compared to the other sampling years.

3.5.3. Comparison of Random Transect Results from 1992 to 2008

A qualitative comparison of the dominant cover components from the random transects showed interesting results for several cover categories: *Montastraea annularis* species complex, macroalgae, and CTB. In 1996 and 1997, no data were recorded for the CTB category (known as reef rock from previous monitoring periods).

The *Montastraea annularis* species complex showed an overall increase in cover during the period from 1992 to 2010 at the WFGB; with the highest cover being recorded in 2010 and an average of approximately 32% cover. Estimates varied at the EFGB but remained consistently at or above 30% (Figure 3.5.2). Estimates for the *M. annularis* species complex were slightly lower in 1996, 1999, and 2003 at the EFGB and in 1996, 2000, 2004, 2007, and 2009 at the WFGB. Higher MASC cover was observed in 1994, 2000, and 2010 at the EFGB and 1994, 2006, and 2010 at the WFGB. Periods of lower coral cover generally coincided with increases in the algal component and decreases in the CTB category. The MASC increases generally coincided with lower macroalgal cover. The results suggest that algal overgrowth can significantly affect estimates of underlying benthic cover, but due to the epemeral nature of algae blooms, does not necessarily lead to long-term reductions in those populations.

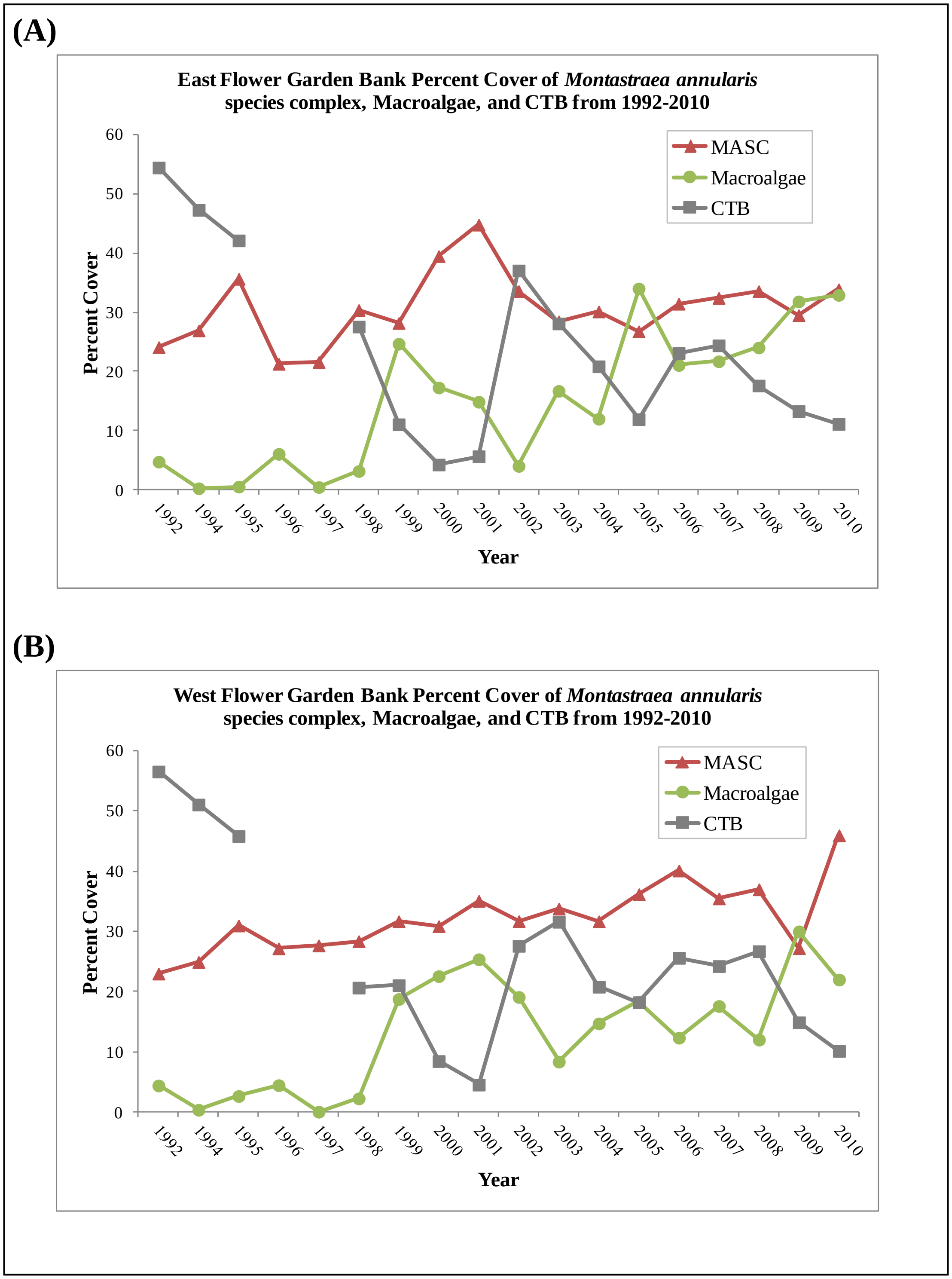


Figure 3.5.2. Percent cover of *Montastraea annularis* species complex, macroalgae, and CTB from 1992 to 2010 at (A) the EFGB and (B) the WFGB.

Local and regional weather patterns affect benthic communities like those at the FGB. Changes in the frequency and severity of the El Niño–Southern Oscillation (ENSO) have been partially responsible for transitions from coral-dominated communities to algae-dominated reef systems in the Caribbean (Glynn 1984, 1993; Goreau and Hayes 1994; Wilkinson and Souter 2008). In 1987, 1995, and 1998, severe ENSO fluctuations affected the western Atlantic, causing large-scale coral bleaching, subsequent coral mortality, and colonization of substrate by algae (Glynn 1984; McField 1999; Aronson et al. 2000). Widespread and severe coral bleaching also occurred in the Caribbean in 2005, but in the absence of an El Niño event (Wilkinson and Souter 2008). The FGB, being a system where these severe effects have not been documented, provides an opportunity to dissect the community dynamics of coral cover, macroalgae, and CTB.

Macroalgae tend to be ephemeral, with different species becoming abundant under certain seasonal conditions (Diaz-Pulido and Garzon-Ferreira 2002). Algae cover at the FGB, here represented primarily within the macroalgae category, remained relatively low until 1999, never reaching more than 6.1% at either bank. It increased dramatically in 1999 and while fluctuating, has remained comparatively high ever since. Average cover has been 15% at EFGB and 13% at WFGB (Table 3.5.2 and Figure 3.5.2). Concurrent with high algae cover, the CTB category was lower at the EFGB in 1999, 2004, and 2010 and at the WFGB in 2000, 2004, and 2010. Overall, the most noticeable pattern was the inverse relationship between coral and macroalgae cover. However, this is a general observation, as coral does not grow and die at the same rate as algae.

Table 3.5.2.

EFGB and WFGB Random Transect Data for Dominant Cover Categories

As reported for 1992 to 1995 in Continental Shelf Associates, Inc. (CSA) (1996); for 1996 to 2001 from Dokken et al. (2003); PBS&J from 2002 to 2008 (Precht et al. 2006, 2008b); and FGBNMS for 2009 to 2010 (this report)

EFGB Random Transect Data			
Year	***Montastraea annularis* species complex**	**Macroalgae**	**CTB**
1992	24.12	4.78	54.46 ± 0.00
1994	26.93	0.29	47.31 ± 0.00
1995	35.65	0.57	42.15 ± 0.00
1996	21.30 ± 14.20	6.10 ± 5.20	-
1997	21.60 ± 8.10	0.50 ± 0.60	-
1998	30.40 ± 11.10	3.20 ± 2.60	27.60 ± 5.90
1999	28.20 ± 11.70	24.70 ± 13.20	11.10 ± 8.20
2000	39.50 ± 9.60	17.30 ± 4.90	4.30 ± 1.70
2001	44.80 ± 12.90	14.90 ± 5.60	5.70 ± 3.60
2002	33.59 ± 3.86	4.06 ± 0.75	37.07 ± 2.69

EFGB Random Transect Data

Year	*Montastraea annularis* species complex	Macroalgae	CTB
2003	28.47 ± 2.98	16.74 ± 2.05	28.12 ± 2.05
2004	30.14 ± 4.76	12.03 ± 2.77	20.89 ± 3.08
2005	26.80 ± 4.09	34.03 ± 2.58	11.96 ± 1.49
2006	31.45 ± 4.09	21.10 ± 2.32	23.15 ± 1.94
2007	32.44 ± 4.62	21.73 ± 2.28	24.43 ± 2.11
2008	33.58 ± 4.52	24.06 ± 2.16	17.64 ± 1.77
2009	29.52 ± 12.99	31.85 ± 3.49	13.32 ± 1.07
2010	33.89 ± 3.84	32.94 ± 3.05	11.15 ± 0.86

WFGB Random Transect Data

Year	*Montastraea annularis* species complex	Macroalgae	CTB
1992	23.02	4.45	56.56
1994	24.95	0.42	51.08
1995	31.0	2.7	45.85
1996	27.20 ± 8.30	4.50 ± 5.20	-
1997	27.70 ± 9.90	0.10 ± 0.60	-
1998	28.40 ± 11.90	2.30 ± 2.60	20.70 ± 5.90
1999	31.70 ± 8.60	18.80 ± 13.20	21.10 ± 8.20
2000	30.90 ± 11.60	22.60 ± 14.00	8.50 ± 3.70
2001	35.10 ± 12.00	25.40 ± 7.30	4.60 ± 2.90
2002	31.73 ± 3.57	19.14 ± 1.40	27.63 ± 3.14
2003	33.80 ± 4.31	8.41 ± 1.41	31.63 ± 3.04
2004	31.70 ± 2.70	14.75 ± 1.50	20.85 ± 2.11
2005	36.20 ± 3.50	18.35 ± 1.44	18.27 ± 1.67
2006	40.13 ± 3.29	12.38 ± 1.34	25.64 ± 2.06
2007	35.50 ± 3.81	17.64 ± 2.44	24.27 ± 1.89
2008	37.01 ± 4.65	12.06 ± 1.31	26.74 ± 2.41
2009	27.25 ± 3.32	30.03 ± 2.63	14.93 ± 1.52
2010	45.98 ± 32.36	22.03 ± 2.00	10.20 ± 1.03

Values listed in table are the mean percent covers for MASC coral cover, macroalgae, and CTB. Standard deviations are shown for 1996 to 2001 based on analysis by Dokken et al. (2003) and standard errors are reported from 2002 to 2010

CHAPTER 4.0: REPETITIVE QUADRATS

4.1. REPETITIVE QUADRAT METHODOLOGICAL RATIONALE

Permanent quadrats, covering 5 m^2 in 2009 and 8 m^2 in 2010, were photographed to monitor changes in the composition of benthic assemblages on the FGB. The repetitive quadrats were located within the EFGB and WFGB study sites, except for the deep stations on the EFGB. Only the central 5 m^2 of the 2010 images was analyzed, as this area provided the clearest resolution for analysis and was comparable to the previous year. The photographs were analyzed in two ways. The first method measured percent benthic cover components in 2009 and 2010 using random-dot analysis. Second, selected corals within the repetitive quadrats were analyzed using planimetry to measure gain or loss of tissue area.

4.2. REPETITIVE QUADRAT FIELD AND LABORATORY METHODS

In 2009, thirty-seven 5 m^2 repetitive quadrats were photographed at each EFGB and WFGB. In 2010, thirty-four and thirty-nine 8 m^2 quadrats were photographed at the EFGB and WFGB respectively (Figure 4.2.1). All nine EFGB deep station quadrats were photographed in both years.

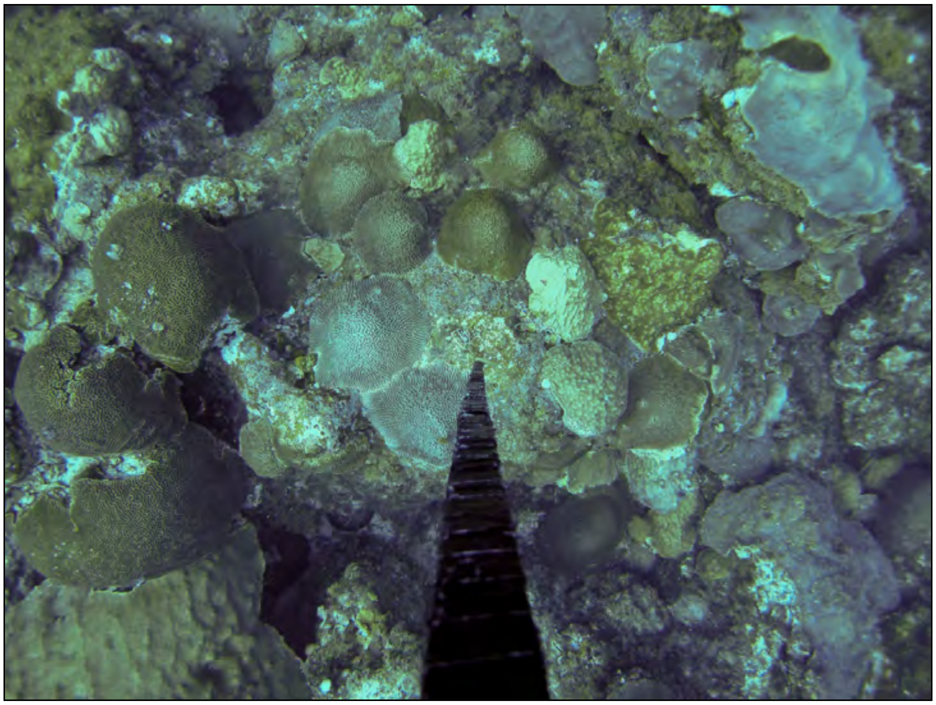


Figure 4.2.1. Repetitive quadrat station #761 at the EFGB in 2009 (NOAA/FGBNMS).

4.2.1. Repetitive Quadrat 2009 Digital Photography

In 2009, stations were photographed using a Nikon Coolpix P5000 camera in an Ikelite housing, with the Inon UWL-100 Type 2 wet mount wide-angle converter lens. The camera was mounted in the center of a T-shaped camera frame, at a distance of 2 m (6.5 ft) from the substrate. Two Ikelite substrobe DS125 strobes were mounted 1.2 m apart on the ends of the T-frame and set on TTL. To ensure that the same quadrats were photographed in the same manner each year, the frame was always oriented in a north-facing direction and kept vertical using an attached bulls-eye bubble level. This set-up produced images with a coverage of 251 x 194 cm.

4.2.2. Repetitive Quadrat 2010 Digital Photography

In 2010, stations were photographed in the same way, but using a Canon Power Shot G11 digital camera in a FIX Fish-Eye housing with a 165° dome port. Because a different lens was used, the distance above the bottom 1.5 m (4.9 ft) and the strobes (Inon Z240) were mounted 1.2 m apart. This set-up produced images with a coverage of 384 x 239 cm.

4.2.3. Repetitive Quadrat Image Analysis

White balance and color correction were applied to each image as necessary. All images were corrected for barrel distortion using Abode® Photoshop® CS5's distortion correction feature. The amount of distortion correction needed was determined by analyzing photographs from pool tests with scale bars. For the 2009 images, no distortion correction was needed because the 2009 camera setup did not use a wide angle lens. For 2010, a distortion correction of +217 was applied to remove the barrel distortion caused by the use of the 165° dome port. In addition, all 2010 images were cropped to match the 2009 repetitive image area. This correction technique removes any error that could occur during percent cover analysis as a result from utilizing different camera setups in 2009 and 2010. However, this does not correct for fine scale differences as seen in the planimetery analysis. This will be addressed in section 4.4.3.

4.2.3.1. Percent Cover of Benthic Components

Coral cover in the images was analyzed using Coral Point Count with Excel® extensions (CPCe) as described in section 3.2.

The percent cover of coral species, sponges, macroalgae, and CTB were determined by overlaying 100 random dots on each photograph using CPCe. This was changed from the previous methodology by Zimmer et al. (2010) where 100 point counts per image were conducted three times. Statistical results from a one-way ANOVA showed there was no significant difference between major cover categories in triplicate compared with single counts for coral species (F=0.03, df=1, P-value >0.86), sponge (F=1.0, df=1, P-value >0.33), macroalgae (F=0.01, df=1, P-value >0.98), and CTB (F=0.07, df=1, P-value >0.79). Therefore, single 100 points were used per picture for the 2009 and 2010 monitoring period. Mean percent cover of corals, sponges, macroalgae, CTB, along with coral bleaching, fish biting, and disease were calculated using 1 x 100 random-dot analysis with CPCe software.

4.2.4. Planimetry Analysis

Planimetry was used to measure percent change in area of living tissue of selected coral colonies (i.e., *Montastraea annularis* species complex, *Diploria strigosa*, *Colpophyllia natans*, *Montastraea cavernosa*, and *Porites astreoides)* at repetitive quadrat stations in successive years. For the 2009 to 2010 interval, it was possible to compare 24 quadrats at the EFGB, and 37 quadrats at the WFGB. For the EFGB deep stations, all nine quadrats were compared for the interval. The 2009 images were scaled to match the area of the 2010 images. This was done in order to obtain a 1:1 pixel ratio between the 2009 and 2010 photos. This was conducted using Adobe Photoshop® CS5 image size feature.

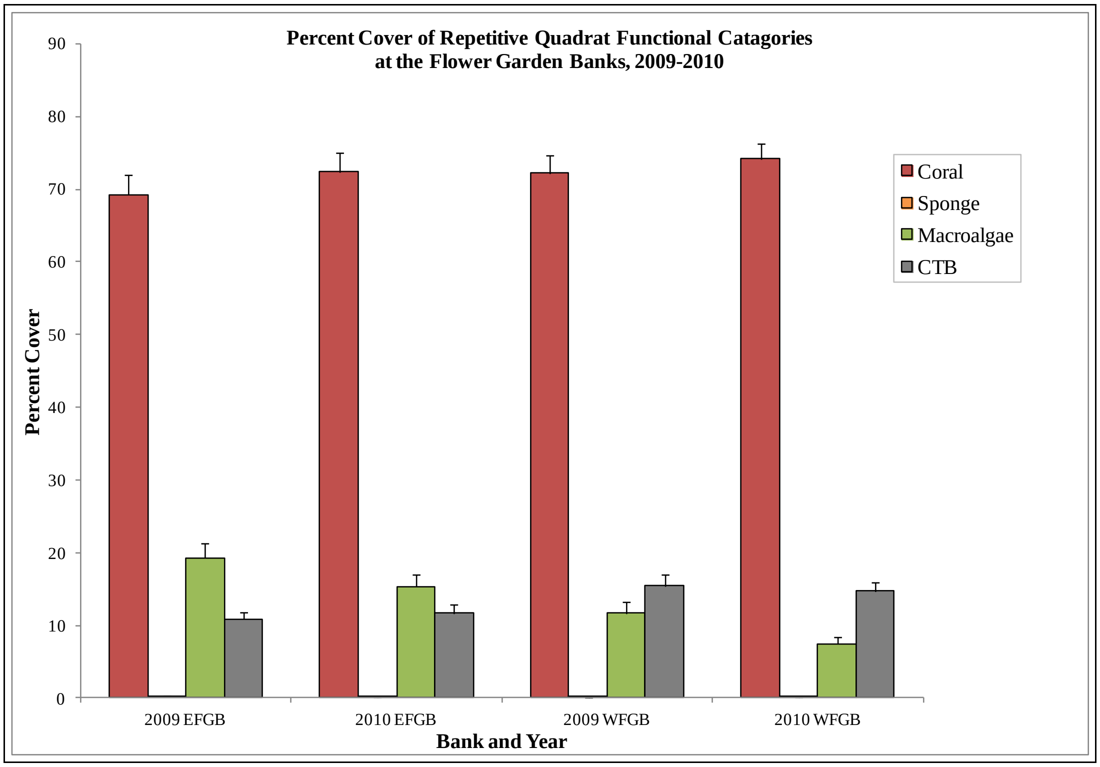
Planimetry results were calculated by taking areal measurements of coral colonies whose lateral margins were contained entirely within the image frame from 2009 and 2010. The live tissue cover of each colony was traced in Adobe Illustrator® CS2 using a Wacom® Cintiq® 12WX Tablet. A mask was then created of the live tissue and areal measurements were calculated using ImageJ®. The percent change in area for each colony was calculated by comparing the area of 2009 to the area of 2010. The change (either positive=growth, or negative=retreat) in pixels was divided by the area (pixels) from 2009 to determine proportional growth or loss of tissue area.

4.3. REPETITIVE QUADRAT RESULTS

4.3.1. Repetitive Quadrat Analysis

4.3.1.1. Percent Cover

The point count data from the repetitive quadrats in the 100 x 100 m study sites were grouped into four functional categories (coral, sponge, macroalgae, and CTB) and expressed as percent covers, the same way the random transect point counts were displayed. In general, repetitive quadrat results from 2009 and 2010 revealed higher coral cover than random transects, low levels of macroalgae (thick turfs and fleshy macroalgal species) and CTB (crustose coralline algae, fine turf algae, and bare rock) cover, and very low coverage of sponges (Figure 4.3.1). The higher coral cover at repetitive stations was to be expected because the stations were originally selected as premium monitoring sites with high coral cover. They were not intended to be representative of average benthic cover.



CTB combines crustose coralline algae, fine turf algae, and bare rock.The "macroalgae" category includes thick turfs as well as fleshy macroalgal species. Values are calculated from the repetitive quadrat photographs.

Figure 4.3.1. Percent cover (+ SE) of four functional categories of sessile benthos at the FGB in 2009 and 2010.

At the EFGB, the results reflected stable coral cover from 2009 to 2010 (69.27% ± 2.69 to 72.41% ± 2.56), while the sponge cover remained extremely low for both years (0.24% ± 0.11 to 0.19% ± 0.08) (Figure 4.3.1 and Table 4.3.1). Macroalgae cover (mainly fleshy algae, turfs, and *Dictyota spp*.) from 2009 to 2010 (19.27% ± 1.98 to 15.37% ± 1.71), and CTB cover remained stable (10.83% ± 0.94 to 11.69% ± 1.14) as well. Consistent with past monitoring results, the *Montastraea annularis* species complex (MASC), containing *M. annularis*, *M. faveolata*, and *M. franksi*, dominated the stations at EFGB in 2009 (46.87% ± 1.56) and 2010 (51.19% ± 1.93). *Diploria strigosa* (11.10% ± 1.83 and 10.25% ± 2.17 in 2009 and 2010, respectively) and *Porites astreoides* (5.00% ± 0.62 in 2009 and 1.74% ± 0.33 in 2010) were the next most abundant taxa (Figure 4.3.2 and Table 4.3.1). The remaining coral cover was made up of eleven species, none of which exceeded 6.0% in either year (Table 4.3.1). Corals that could not be differentiated because of camera angle or camera distortion were labeled as "unidentified coral." Shannon-Weiner diversity values remained consistent at the EFGB (H'= 0.76 and H'= 0.73 in 2009 and 2010, respectively).

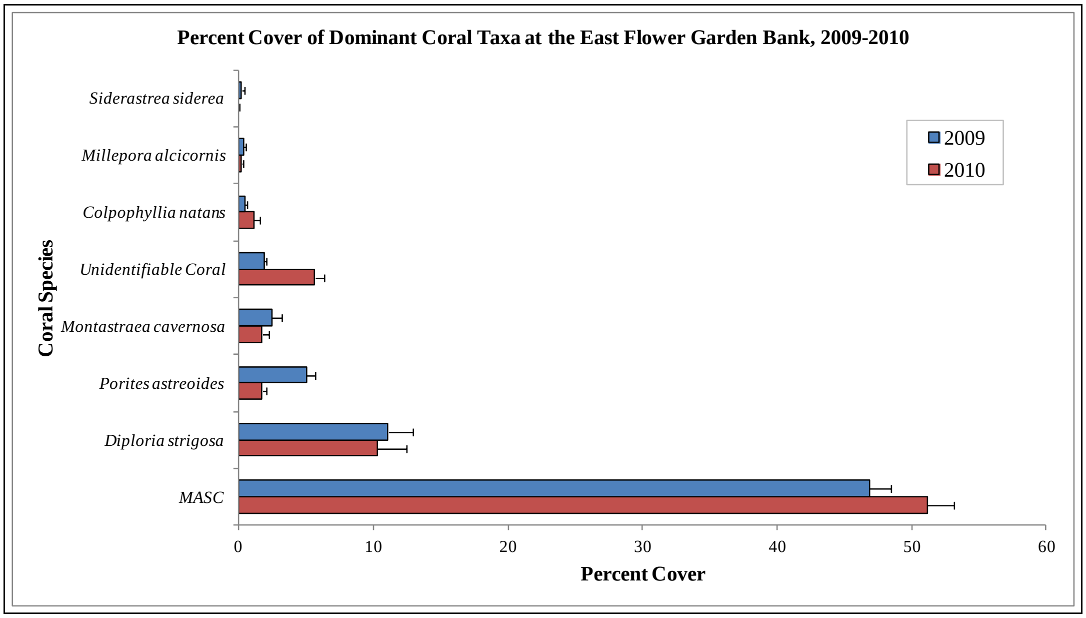


Figure 4.3.2. Percent cover (+ SE) of the dominant coral taxa in repetitive quadrats at the EFGB in 2009 and 2010.

In quadrats at the WFGB, coral cover remained consistent from 2009 (72.19% ± 2.48) to 2010 (74.19% ± 2.07). The sponge cover remained extremely low for both years at the WFGB (0.03% ± 0.03 to 0.11% ± 0.06) (Figure 4.3.1 and Table 4.3.1). Macroalgae cover decreased from 2009 to 2010 (11.65% ± 1.53 to 7.46% ± 1.01), while CTB cover remained stable (15.41% ± 1.51 to 14.69% ± 1.21). As with the EFGB, the *Montastraea annularis* species complex dominated quadrats at the WFGB in 2009 (48.36% ± 1.85) and 2010 (45.69% ± 1.81). *Diploria strigosa* (10.24% ± 1.89 and 7.84% ± 1.23 in 2009 and 2010, respectively) and *Porites astreoides* (4.29% ± 0.62 in 2009 and 2.49% ± 0.56 in 2010) were the next most abundant species (Figure 4.3.3 and Table 4.3.1). *Montastraea cavernosa* was also abundant in 2009 (3.41% ± 0.92) and 2010 (4.47% ± 1.16). The remaining coral cover was made up of eleven species, none of which exceeded 10.0% in either year (Table 4.3.1). Shannon-Weiner diversity values remained consistent at the WFGB (H'=0.73 and H'=0.70 in 2009 and 2010, respectively).

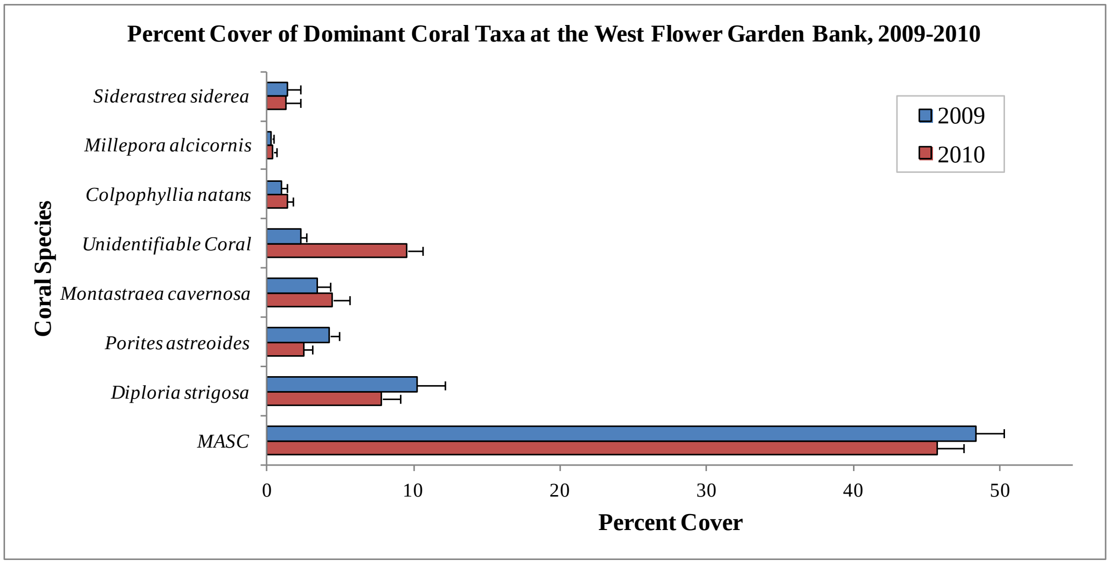


Figure 4.3.3. Percent cover (+ SE) of the dominant coral taxa in repetitive quadrats at the WFGB in 2009 and 2010.

Table 4.3.1.

Cover of Benthic Categories in Repetitive Quadrats at the EFGB and WFGB in 2009 and 2010

Values are expressed as percent cover ± SE

Cover Category	2009 EFGB	2010 EFGB	2009 WFGB	2010 WFGB
Coral				
Montastraea annularis species complex (MASC)	46.87 ± 1.56	51.19 ± 1.93	48.36 ± 1.85	45.69 ± 1.81
Diploria strigosa	11.10 ± 1.83	10.25 ± 2.17	10.24 ± 1.89	7.84 ± 1.23
Porites astreoides	5.00 ± 0.62	1.74 ± 0.33	4.29 ± 0.62	2.49 ± 0.56
Montastraea cavernosa	2.43 ± 0.74	1.72 ± 0.52	3.41 ± 0.92	4.47 ± 1.16
Unidentifiable Coral	1.86 ± 0.22	5.63 ± 0.72	2.30 ± 0.38	9.56 ± 1.06
Colpophyllia natans	0.45 ± 0.17	1.10 ± 0.45	0.96 ± 0.36	1.36 ± 0.45
Millepora alcicornis	0.36 ± 0.15	0.21 ± 0.09	0.29 ± 0.12	0.43 ± 0.18
Madracis spp.	0.32 ± 0.27	0.10 ± 0.06	0.19 ± 0.09	0.06 ± 0.06
Agaricia spp.	0.26 ± 0.17	0.04 ± 0.04	0.11 ± 0.09	0.04 ± 0.04
Siderastrea siderea	0.20 ± 0.17	0.00	1.39 ± 0.87	1.30 ± 0.96
Stephanocoenia intersepta	0.15 ± 0.12	0.00	0.40 ± 0.18	0.24 ± 0.12
Mussa angulosa	0.07 ± 0.05	0.11 ± 0.06	0.18 ± 0.13	0.13 ± 0.07
Porites furcata	0.03 ± 0.03	0.00	0.00	0.00
Siderastrea spp.	0.03 ± 0.03	0.09 ± 0.07	0.08 ± 0.05	0.26 ± 0.14
Scolymia spp.	0.00	0.03 ± 0.03	0.00	0.03 ± 0.03
Total Coral	69.27 ± 2.69	72.41 ± 2.56	72.19 ± 2.48	74.19 ± 2.07
Sponge				
Agelas clathrodes	0.11 ± 0.08	0.04 ± 0.04	0.00	0.11 ± 0.06
Chondrilla brown	0.06 ± 0.04	0.11 ± 0.06	0.00	0.00
Arolochroia (Pseudoceratina) crassa	0.04 ± 0.04	0.00	0.00	0.00
Unknown Sponge I	0.03 ± 0.03	0.04 ± 0.04	0.03 ± 0.03	0.00
Encrusting sponge	0.00	0.07 ± 0.05	0.08 ± 0.05	0.52 ± 0.18
Total Sponge	0.24 ± 0.11	0.19 ± 0.08	0.03 ± 0.03	0.11 ± 0.06
CTB				
Bare Substrate	8.47 ± 0.86	4.53 ± 0.82	9.91 ± 1.14	3.24 ± 0.34
Fine Turf	2.33 ± 0.46	3.03 ± 0.62	4.29 ± 1.09	6.98 ± 0.92
Crustose Coralline Algae	0.00	4.05 ± 0.50	0.00	4.47 ± 0.70
Total CTB	10.83 ± 0.94	11.69 ± 1.14	15.41 ± 1.51	14.69 ± 1.21
Macroalgae				
Fleshy algae	15.84 ± 1.64	10.39 ± 1.24	10.45 ± 1.35	5.73 ± 0.81
Dictyota spp.	1.97 ± 0.53	3.35 ± 0.76	0.40 ± 0.14	0.40 ± 0.13
Thick turf algae	1.04 ± 0.37	1.59 ± 0.41	0.08 ± 0.08	1.28 ± 0.32
Lobophora variegata	0.39 ± 0.13	0.05 ± 0.05	0.72 ± 0.23	0.05 ± 0.05

Cover Category	2009 EFGB	2010 EFGB	2009 WFGB	2010 WFGB
Filamentous algae	0.03 ± 0.03	0.00	0.00	0.00
Total Macroalgae	19.27 ± 1.98	15.37 ± 1.71	11.65 ± 1.53	7.46 ± 1.01
Other				
Shadow	14.63 ± 1.26	22.00 ± 1.86	15.35 ± 0.83	26.36 ± 1.61
Sand	0.14 ± 0.10	0.28 ± 0.20	0.35 ± 0.21	2.91 ± 1.65
Substrate Rubble	0.00	0.03 ± 0.03	1.21 ± 0.73	0.00
Fish	0.06 ± 0.06	0.00	0.25 ± 0.10	0.03 ± 0.03
Invertebrate	0.18 ± 0.08	0.00	0.03 ± 0.03	0.10 ± 0.08
Coral Condition (occurences in coral)				
Bleached Coral	0.05 ± 0.04	0.03 ± 0.03	0.00	1.90 ± 0.38
Paling Coral	0.82 ± 0.39	0.43 ± 0.18	0.50 ± 0.18	2.77 ± 0.62
Concentrated Fish Biting	0.03 ± 0.03	0.00	0.03 ± 0.03	0.03 ± 0.03
Isolated Fish Biting	0.03 ± 0.03	0.03 ± 0.03	0.00	0.03 ± 0.03

The combined data collected in 2009 and 2010 showed persistence of the *Montastraea annularis* species complex as the dominant coral species in the repetitive quadrats at the EFGB and WFGB (Table 4.3.1). *Diploria strigosa* was the second-most prevalent coral species during this time period. *Porites astreoides* and *M. cavernosa* were consistently the third and fourth most abundant corals. The average coral cover in quadrats at both banks was approximately 72% for the reporting period. This was much higher than the average random transect coral cover for both banks during the reporting period (~57%), but as explained above, the coral in the repetitive stations were selected partly because of their high coral cover. Appendix 4 contains the repetitive quadrat data for 2009 and 2010 at the FGB.

In past monitoring years, the *Montastraea annularis* species complex (*M. annularis*, *M. faveolata*, and *M. franksi*) were not differentiated, but with higher resolution digital photography and the familiarity of the FGBNMS staff with the photostations, the components of the *Montastraea annularis* species complex were indentified in the repetitive quadrat photographs. At both banks, the *Montastraea annularis* species complex is dominated by *M. franksi*, followed by *M. faveolata* and *M. annularis*. At the EFGB, *M. franksi* percent cover was similar in 2009 and 2010 (35.50% ± 3.40 to 37.19% ± 3.82), and *M. faveolata* (3.99% ± 1.11 to 2.81% ± 1.01) remained stable as well. *M. annularis* was not sampled in 2009, but was identified in 2010 (3.03% ± 1.42) (Figure 4.3.4). At the WFGB, *M. franksi* percent cover was slightly lower in 2010 (35.21% ± 3.62 to 31.76% ± 2.72), while *M. annularis* (3.44% ± 1.43 to 5.26% ± 2.00) and *M. faveolata* (0.40% ± 0.26 to 1.05% ± 0.81) remained relatively stable (Figure 4.3.5). Approximately 8.0% of the individual MASC components still could not be identified, which may be due to MASC hybridization or genotypic variation.

In the repetitive quadrat in 2009 and 2010, the incidences of bleaching, paling, and fish biting were low at both banks and coral disease was absent (Table 4.3.1). The percentage of corals impacted by isolated/concentrated fish biting at the EFGB and WFGB was negligible, ranging from 0.00 to 0.03%. Less than 3% of the coral cover analyzed in the random transect percent cover analysis exhibited disease or bleaching at the EFGB and WFGB in either year (Figure 4.3.6).

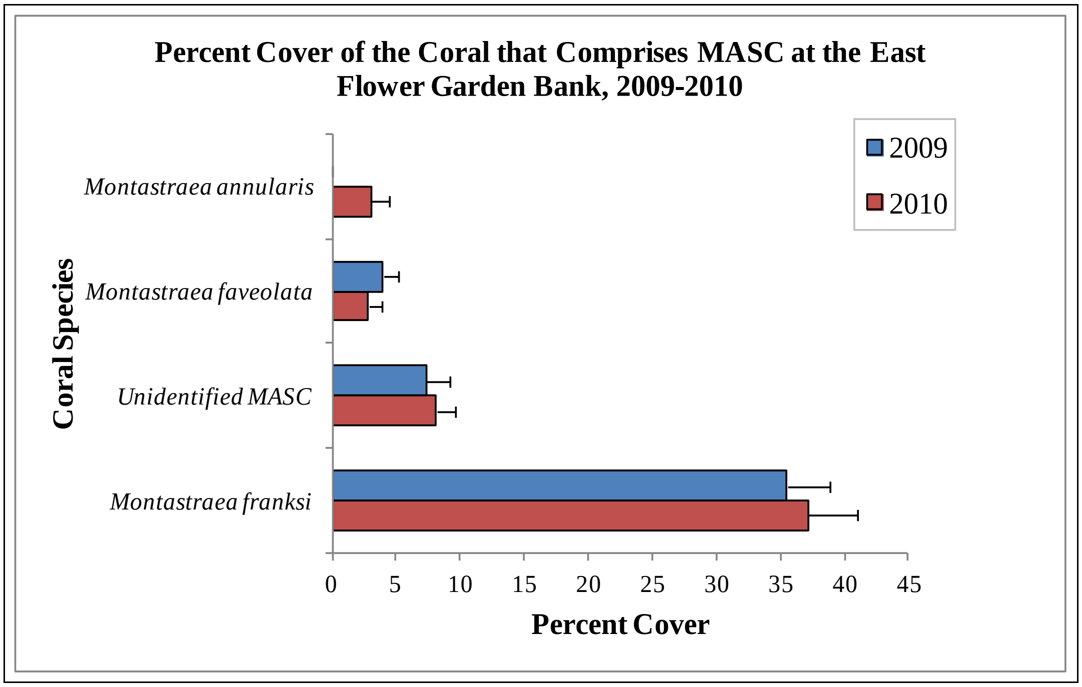


Figure 4.3.4. Percent cover (+ SE) of the coral species in the MASC in repetitive quadrats at the EFGB in 2009 and 2010.

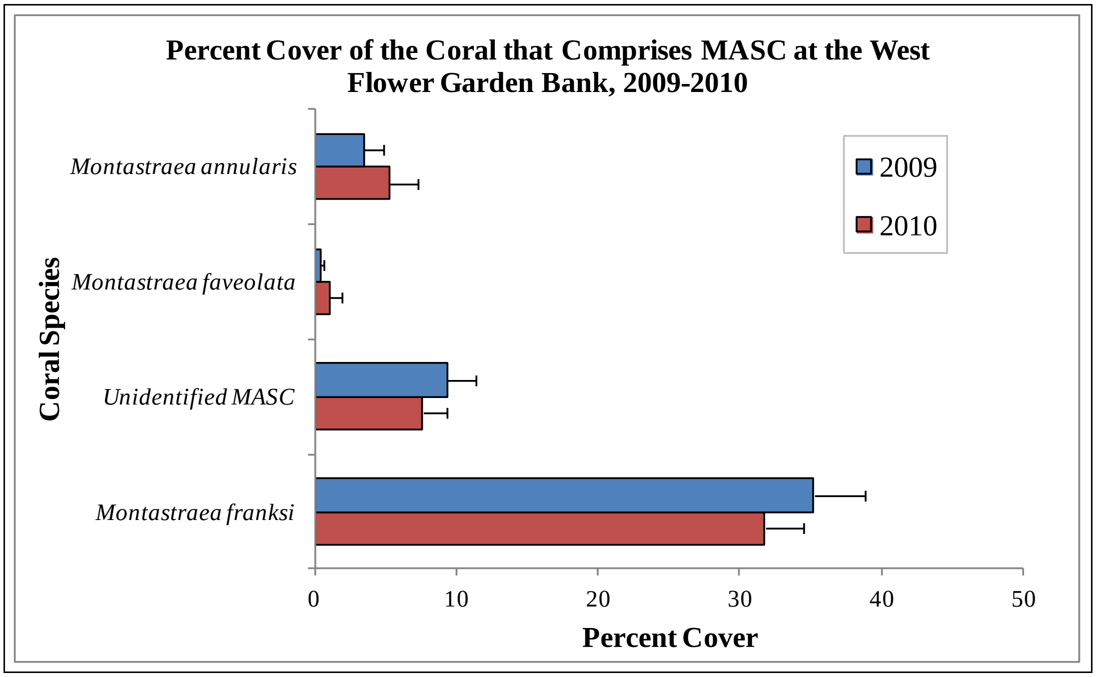


Figure 4.3.5. Percent cover (+ SE) of the coral species in the MASC in repetitive quadrats at the WFGB in 2009 and 2010.

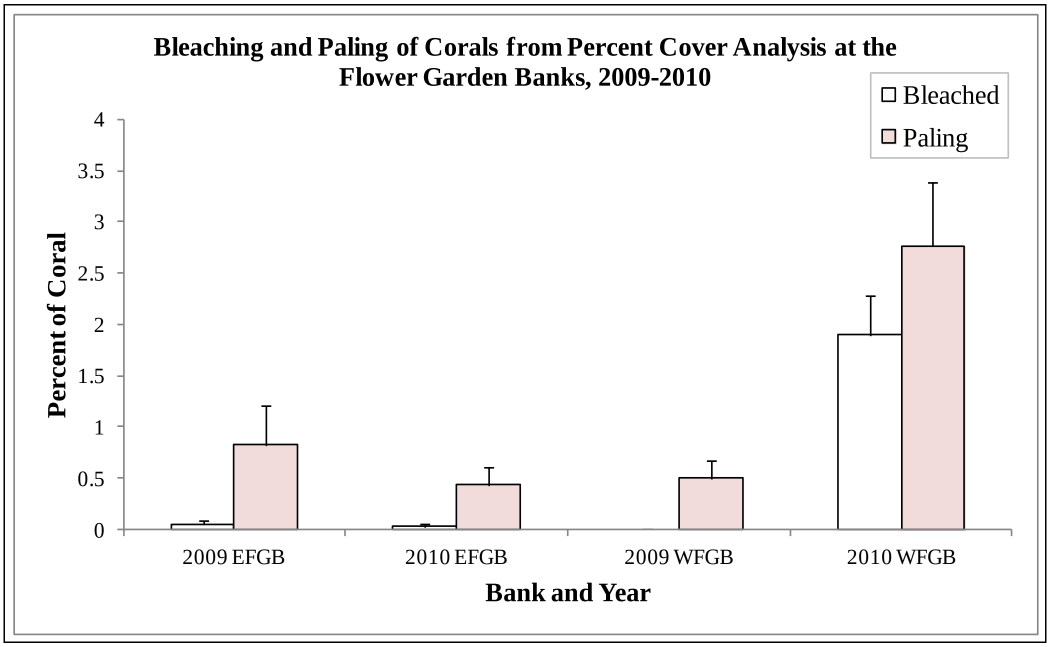
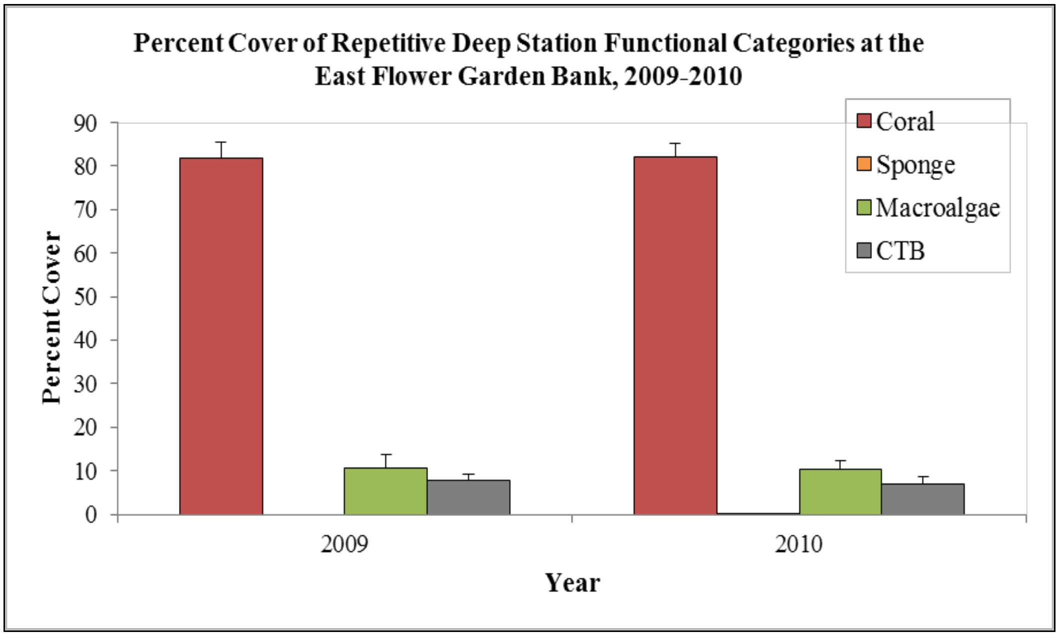


Figure 4.3.6. Percent of coral observed to pale and bleach (+ SE) in repetitive quadrats at the FGB in 2009 and 2010.

4.3.1.2. Deep Stations–Percent Cover

All nine EFGB deep station quadrats were photographed in both years and analyzed for benthic cover using random dot analysis. The point count data were grouped into the same four functional categories (coral, sponge, macroalgae, and CTB) and expressed as percent covers, the same way the random transect point counts were displayed. Coral cover was very high at the deep stations (ranging from 81–82% between 2009 and 2010), and sponge cover was extremely low (0.00–0.25%). Coral cover was followed by low levels of macroalgae and CTB cover (Figure 4.3.7). High levels of coral cover were consistent with past monitoring results. Unlike the repetitive stations in the shallower study sites, however, which were chosen because of the presence of high cover, these stations were selected to show representative areas of the deep reef. Therefore, the high coral cover at these stations may be more indicative of average conditions at these depths on the bank.



CTB includes crustose coralline algae, fine turf algae, and bare rock. The "macroalgae" category includes thick turfs as well as fleshy macroalgal species. Values are calculated from the repetitive quadrat deep station photographs.

Figure 4.3.7. Percent cover (+ SE) of four functional categories of sessile benthos at the EFGB repetitive deep stations in 2009 and 2010.

Coral cover remained stable from 2009 to 2010 (81.73% ± 3.90 to 82.18% ± 3.01). Sponge cover was not detected in 2009, and only minimally observed in 2010 (0.25% ± 0.25) (Figure 4.3.7 and Table 4.3.2). Macroalgae cover (mainly fleshy algae, turfs, and *Dictyota* spp.) remained stable from 2009 to 2010 (10.56% ± 3.12 to 10.28% ± 2.06), as did CTB cover (7.72% ± 1.39 to 6.98% ± 1.53).

Consistent with past monitoring results, the *Montastraea annularis* species complex (MASC) continued to dominate the EFGB repetitive deep stations in 2009 (51.70% ± 4.38) and 2010 (46.70% ± 3.54). *Montastraea cavernosa* (15.42% ± 4.16 and 10.65% ± 3.69 in 2009 and 2010, respectively) and *Colpophyllia natans* (5.10% ± 2.06 in 2009 and 5.75% ± 3.44 in 2010) were the next most abundant species (Figure 4.3.8 and Table 4.3.2). *Montastraea cavernosa* was also more dominant in the EFGB deep stations than on the reef cap. The remaining coral cover was made up of twelve species, none of which exceeded than 2% in either year (Table 4.3.2). Corals that could not be differentiated due to camera angle or camera distortion were label as "unidentifiable coral."

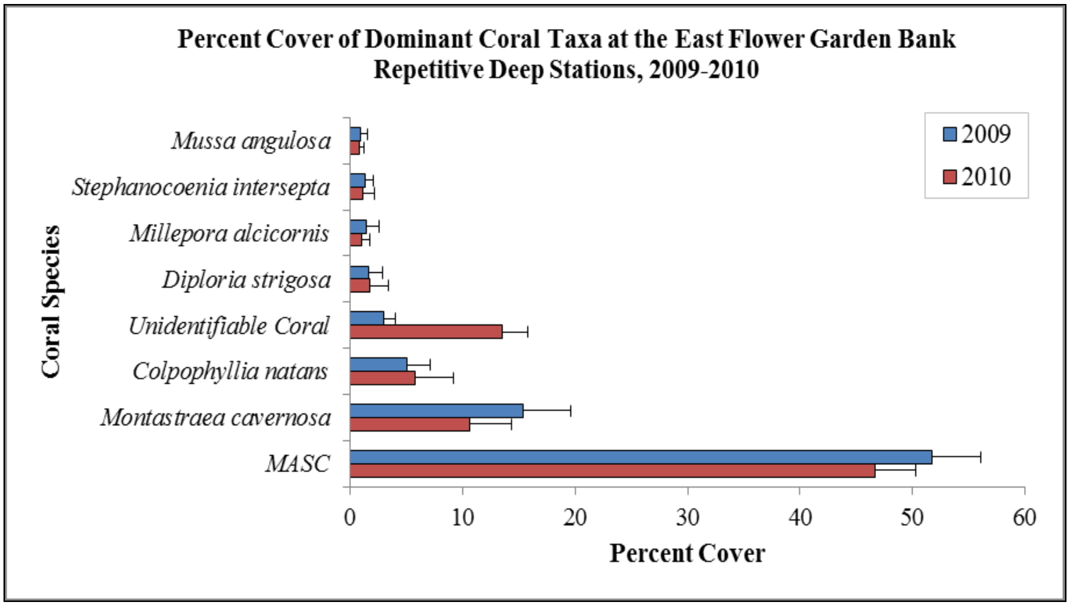


Figure 4.3.8. Percent cover (+ SE) of the dominant coral taxa at repetitive deep stations on the EFGB in 2009 and 2010.

Table 4.3.2.

Cover of Benthic Categories in Repetitive Deep Stations at the EFGB from 2009 and 2010

Values are expressed as percent cover ± SE

Cover Category	2009 EFGB Deep Station	2010 EFGB Deep Station
Coral		
Montastraea annularis species complex (MASC)	51.70 ± 4.38	46.70 ± 3.54
Montastraea cavernosa	15.42 ± 4.16	10.65 ± 3.69
Colpophyllia natans	5.01 ± 2.06	5.75 ± 3.44
Unidentifiable Coral	2.96 ± 1.07	13.56 ± 2.22
Diploria strigosa	1.69 ± 1.18	1.75 ± 1.61
Millepora alcicornis	1.40 ± 1.14	1.07 ± 0.63
Stephanocoenia intersepta	1.32 ± 0.71	1.16 ± 0.99
Mussa angulosa	0.96 ± 0.60	0.79 ± 0.45
Agaricia spp.	0.65 ± 0.65	0.16 ± 0.16
Scolymia cubensis	0.36 ± 0.25	0.00
Madracis decactis	0.13 ± 0.13	0.00
Scolymia spp.	0.12 ± 0.12	0.00
Agaricia undata	0.00	0.16 ± 0.16
Porites astreoides	0.00	0.16 ± 0.16
Paracyanthus pulchellus	0.00	0.13 ± 0.13
Siderastrea siderea	0.00	0.12 ± 0.12
Total Coral	81.73 ± 3.90	82.18 ± 3.01
SPONGE		
Ircinia felix	0.00	0.13 ± 0.13
Ircinia strobilina	0.00	0.13 ± 0.13
Total Sponge	0.00	0.25 ± 0.25
CTB		
Bare Substrate	3.53 ± 0.92	3.45 ± 0.74
Fine Turf	3.18 ± 0.92	1.48 ± 0.71
Crustose Coralline Algae	0.00	2.05 ± 0.74
Total CTB	7.72 ± 1.39	6.98 ± 1.53
Macroalgae		
Fleshy algae	5.47 ± 1.35	7.69 ± 1.58
Lobophora variegata	1.82 ± 0.74	2.07 ± 0.72
Think turf algae	1.78 ± 0.62	0.13 ± 0.13
Dictyota spp.	1.49 ± 0.99	0.26 ± 0.17
Peysonnelia spp.	0.00	0.13 ± 0.13

Cover Category	2009 EFGB Deep Station	2010 EFGB Deep Station
Total Macroalgae	10.56 ± 3.12	10.28 ± 2.06
Other		
Shadow	6.78 ± 1.90	18.56 ± 2.95
Coral Rubble	0.76 ± 0.76	0.00
Substrate Rubble	0.25 ± 0.17	0.00
Sand	0.00	0.14 ± 0.14
Coral Condition (occurences in coral)		
Bleached Coral	0.00	0.00
Paling Coral	2.67 ± 1.46	1.89 ± 1.09
Concentrated Fish Biting	0.22 ± 0.22	0.00
Isolated Fish Biting	0.00	0.00

At the deep stations on the EFGB, the *Montastraea annularis* species complex is dominated by *M. franksi*, followed by *M. faveolata*. *M. franksi* dominated the MASC cover (45.37% ± 6.19 in 2009 and 25.32% ± 4.49 in 2010). *M. faveolata* was not detected in 2009, but was detected in 2010 (1.40% ± 1.40) (Figure 4.3.9). *M. annularis* was not identified in 2009 or 2010; however, 6.33% of the individual MASC components were unidentifiable in 2009, and 19.98% of the components were unidentifiable in 2010. This may also be due to MASC hybridization or genotypic variation.

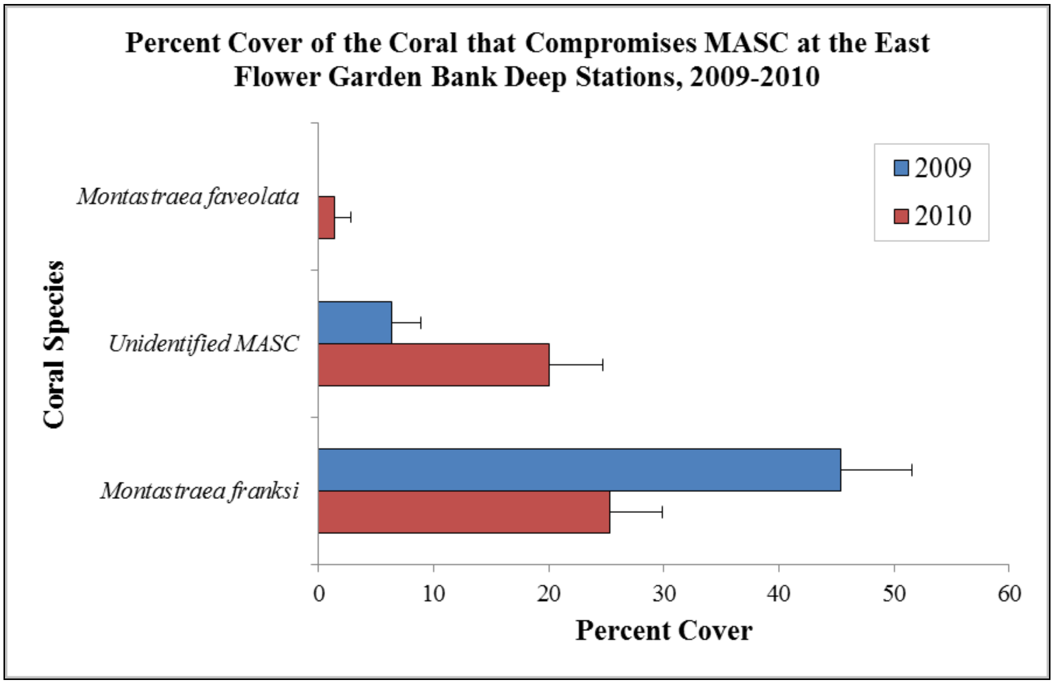


Figure 4.3.9. Percent cover (+ SE) of the coral species that comprises the MASC at deep repetitive stations the EFGB deep stations from 2009 and 2010.

In the 2009 and 2010 repetitive deep stations, evidence of coral disease was absent (Table 4.3.2). The percentage of corals impacted by isolated/concentrated fish biting was negligible, ranging from 0.00 to 0.22%. Less than 3% of the coral cover analyzed in the deep stations exhibited paling or bleaching.

4.3.2. Repetitive Quadrat Planimetric Analysis

Some corals in repetitive quadrat photographs were analyzed using planimetry. Measurements of the amount of change in living area on selected coral colonies were conducted to document the dynamics of particular coral colonies at the EFGB (cap and deep stations) and WFGB. Changes were also assessed visually to either verify or refute planimetric measurements. Staff chose and identified coral colonies with discernable margins to be measured for planar areal change from 2009 to 2010. In each frame, one to four colonies of framework-building corals, where the margins were clearly defined, were chosen for analysis. *Montastraea annularis* species complex, the main contributor to coral cover at the FGB, along with *Diploria strigosa* and *Porites asteroides* colonies were the most common colonies selected (Table 4.3.3).

Table 4.3.3.

Reef-Building Coral Colonies in Photographs from Repetitive Quadrat Stations Selected for Planimetric Analysis from 2009 to 2010

Bank	**Coral Colonies Chosen for Planimetric Analysis**				
	Station Number	**Coral 1**	**Coral 2**	**Coral 3**	**Coral 4**
EAST BANK	001	*M. cavernosa*	*P. astreoides*		
	003	*D. strigosa*	*P. asteroides*	*P. astreoides*	*M. franksi*
	005	*C. natans*	*M. faveolata*	*P. astreoides*	*P. astreoides*
	010	*C. natans*	*P. astreoides*	*P. astreoides*	
	016	*M. franksi*	*P. astreoides*	*D. strigosa*	
	020	*P. astreoides*	*P. astreoides*	*P. astreoides*	*D. strigosa*
	021	*P. astreoides*	*M. franksi*	*P. astreoides*	*M. franksi*
	027	*D. strigosa*	*D. strigosa*	*C. natans*	
	029	*M. franksi*	*P. astreoides*	*D. strigosa*	
	032	*M. faveolata*	*M. faveolata*	*P. astreoides*	*M. franksi*
	058	MASC	*M. cavernosa*	*P. astreoides*	
	067	*D. strigosa*	*P. astreoides*	*D. strigosa*	
	185	*P. astreoides*	*D. strigosa*	*P. astreoides*	
	715	*D. strigosa*	*D. strigosa*	MASC	
	717	*D. strigosa*	*P. astreoides*		
	725	*P. astreoides*	*M. franksi*	*C. natans*	
	739	*M. cavernosa*	*M. franksi*	*P. astreoides*	
	751	*M. franksi*	*M. annularis*	*P. astreoides*	*M. annularis*

Bank	**Coral Colonies Chosen for Planimetric Analysis**				
	Station Number	**Coral 1**	**Coral 2**	**Coral 3**	**Coral 4**
	755	*P. astreoides*	*D. strigosa*	*P. astreoides*	
	756	*C. natans*	*M. franksi*	*P. astreoides*	
	757	*P. astreoides*	*D. strigosa*	*M. franksi*	
	761	*C. natans*	*D. strigosa*	*M. franksi*	*P. astreoides*
	764	*M. franksi*	*P. astreoides*	*D. strigosa*	*P. astreoides*
	765	*P. astreoides*	*M. cavernosa*	*P. astreoides*	
DEEP STATIONS	081	*C. natans*	*C. natans*		
	082	*M. angulosa*	*C. natans*	MASC	
	083	*M. franksi*	*M. cavernosa*	*M. cavernosa*	
	084	*M. cavernosa*	*M. cavernosa*	*M. faveolata*	
	085	*M. cavernosa*	*M. faveolata*	*M. cavernosa*	
	086	*M. franksi*	*M. cavernosa*		
	087	*M. franksi*	MASC	*P. astreoides*	MASC
	088	*D. strigosa*	*M. franksi*		
	089	*M. cavernosa*	*M. franksi*	*M. cavernosa*	
WEST BANK	018	*P. astreoides*	*P. astreoides*	*P. astreoides*	*P. astreoides*
	041	*M. faveolata*	*M. franksi*	*P. astreoides*	
	042	*P. astreoides*	MASC	*M. cavernosa*	
	045	*M. franksi*	*P. astreoides*	*D. strigosa*	
	046	*M. franksi*	*P. astreoides*	*C. natans*	
	049	*D. strigosa*	*M. cavernosa*	*P. astreoides*	
	051	*P. astreoides*	*D. strigosa*	*D. strigosa*	
	054	*P. astreoides*	*P. astreoides*	*P. astreoides*	
	061	*M. annularis*	*P. astreoides*	*M. annularis*	
	072	*P. astreoides*	*D. strigosa*	*D. strigosa*	*D. strigosa*
	073	*D. strigosa*	*M. franksi*	*D. strigosa*	
	091	*D. strigosa*	*D. strigosa*	*D. strigosa*	
	093	*P. astreoides*	*D. strigosa*	*P. astreoides*	
	125	*P. astreoides*	*C. natans*	*P. astreoides*	
	822	*D. strigosa*	*D. strigosa*	*M. franksi*	
	824	*S. intersepta*	*P. astreoides*	*M. annularis*	
	839	*M. franksi*	*M. franksi*	*D. strigosa*	
	843	*P. astreoides*	*D. strigosa*	*D. strigosa*	
	844	*P. astreoides*	*P. astreoides*	*P. astreoides*	
	847	*P. astreoides*	*P. astreoides*	*D. strigosa*	
	848	*D. strigosa*	*P. astreoides*	*D. strigosa*	

Bank	Coral Colonies Chosen for Planimetric Analysis				
	Station Number	**Coral 1**	**Coral 2**	**Coral 3**	**Coral 4**
	857	*C. natans*	*M. franksi*	*M. franksi*	
	861	*M. franksi*	*P. astreoides*	*P. astreoides*	
	862	*P. astreoides*	*P. astreoides*	*M. franksi*	
	865	*D. strigosa*	*P. astreoides*	*D. strigosa*	
	866	*S. intersepta*	*D. strigosa*	*P. astreoides*	
	867	*M. franksi*	*D. strigosa*		
	868	*P. asteroides*	*P. asteroides*	*P. astreoides*	
	869	*M. annularis*			
	870	*P. astreoides*	*P. astreoides*	*P. astreoides*	*P. astreoides*
	874	*M. faveolata*	*M. annularis*	*P. astreoides*	
	875	*P. astreoides*	*M. franksi*	*D. strigosa*	
	876	*P. astreoides*	*P. astreoides*		
	877	*P. astreoides*	*C. natans*	*M. franksi*	
	878	*M. franksi*	*M. franksi*	*M. franksi*	
	879	*M. franksi*	*D. strigosa*	*M. franksi*	
	NT3	*D. strigosa*	*P. astreoides*	*P. astreoides*	

On average, coral colonies selected for analysis at the EFGB and WFGB were found to have decreased in area. However, visual photohraphics assessments of all the analyzed coral colonies suggested that most of the coral colonies did not suffer as much tissue loss as the planimetric analysis suggested (Table 4.3.4). The problems with the calculations of area lost or gained from 2009 to 2010 are thought to arise from using different camera setups in the two years and previous analog versus digital photos from previous monitoring periods. No statistical analyses were run on the data because of issues with image distortion and differing heights of the camera above the bottom derived from changing camera setups between years resulting in corals to appear at different angles. These issues are addressed further in the discussion section.

Table 4.3.4.

Visual Assessment of Analyzed Coral Colonies Suggest Colonies Did Not Suffer As Much Tissue Loss as the Planimetric Analysis Suggested

Highlighted cells suggest causes or consequences of change; blue cells represent growth and yellow loss

Bank	**Station Number**	**Coral 1**	**Coral 2**	**Coral 3**	**Coral 4**
EAST BANK	001	Tissue growth in some bare areas	No detectable change		
	003	No detectable change	No detectable change	No detectable change	No detectable change
	005	No detectable change	Small growth around bare areas	Loss of tissue on margin	Small loss of tissue on cracks
	010	Loss of tissue and increase in orange sponge	No detectable change	No detectable change	
	016	No detectable change	No detectable change	No detectable change	
	020	No detectable change	No detectable change	No detectable change	No detectable change
	021	Small tissue loss	No detectable change	No detectable change	No detectable change
	027	Small growth on margins, filling in gaps	Small loss of tissue on margin, next to *M. franksi*	No detectable change	
	029	Bare areas filling in with live tissue	No detectable change	No detectable change	
	032	Concentrated fish biting healed	No detectable change	No detectable change	No detectable change
	058	No detectable change	Tissue loss in center of head, overgrown with algae	No detectable change	
	067	Small tissue loss, possible fish biting	Small growth around margins	No detectable change	
	185	No detectable change	No detectable change	Large tissue loss, overgrown with algae	
	715	No detectable change	Large tissue loss, CCA / algae growing on dead coral	No detectable change	
	717	No detectable change	Small tissue loss on margins		
	725	No detectable change	No detectable change	Loss of tissue	
	739	No detectable change	No detectable change	No detectable change	

Bank	Station Number	Coral 1	Coral 2	Coral 3	Coral 4
	751	Small tissue loss	No detectable change	No detectable change	Tissue growing over bare area
	755	No detectable change	No detectable change	No detectable change	
	756	No detectable change	No detectable change	Small growth on margin	
	757	Small loss of tissue; possible fish biting	Coral looks healthier; tissue growth over cracks; discoloration gone	Tissue growth in previous voids	
	761	Some discoloration on N margin	Small tissue loss in crack on S margin	No detectable change	Tissue growth filling in cracks
	764	No detectable change	Small loss of tissue on margin near Coral 3	No detectable change	No detectable change
	765	No detectable change	No detectable change	Large tissue loss	
DEEP STATIONS	081	No detectable change	No detectable change		
	082	Small loss of tissue	No detectable change	No detectable change	
	083	No detectable change	No detectable change	Small loss of tissue; fish biting	
	084	Small tissue loss; fish biting	No detectable change	No detectable change	
	085	No detectable change	No detectable change	Small growth of tissue in bare areas	
	086	No detectable change	No detectable change		
	087	Small tissue loss, possible fish biting	No detectable change	No detectable change	No detectable change
	088	No detectable change	No detectable change		
	089	Tissue loss; overgrown with algae	No detectable change	Tissue loss; fish biting	
WEST BANK	018	No detectable change	No detectable change	No detectable change	No detectable change
	041	No detectable change	No detectable change	No detectable change	
	042	No detectable change	Large tissue growth into previously bare areas	No detectable change; coral paling	

Bank	Station Number	Coral 1	Coral 2	Coral 3	Coral 4
	045	No detectable change	Small loss of tissue	No detectable change	
	046	Small recovery of tissue	No detectable change	No detectable change	
	049	No detectable change	Large loss of tissue on apex	No detectable change	
	051	No detectable change	No detectable change	Small tissue growth	
	054	No detectable change	Small tissue growth	No detectable change	
	061	Small loss of tissue	No detectable change	No detectable change	
	072	No detectable change	No detectable change	No detectable change	No detectable change
	073	Tissue growth into bare areas	Tissue loss	Tissue loss	
	091	No detectable change	No detectable change	No detectable change	
	093	No detectable change	Small tissue loss	No detectable change	
	125	No detectable change	Small loss of tissue on margins	No detectable change	
	822	No detectable change	No detectable change	No detectable change	
	824	No detectable change	Small loss of tissue	Loss of tissue; overgrown with algae	
	839	No detectable change	No detectable change	No detectable change	
	843	Small growth of tissue	No detectable change	No detectable change	
	844	Small loss of tissue on margin	No detectable change	No detectable change	
	847	No detectable change	No detectable change	No detectable change	
	848	No detectable change	No detectable change	No detectable change	
	857	Loss of tissue	No detectable change	No detectable change	
	861	Small growth of tissue	Loss of tissue	No detectable change	
	862	No detectable change	No detectable change	No detectable change	
	865	No detectable change	No detectable change	No detectable change	
	866	No detectable change	No detectable change	No detectable change	
	867	Tissue growth	Small tissue loss		
	868	No detectable change	No detectable change	No detectable change	

Bank	Station Number	Coral 1	Coral 2	Coral 3	Coral 4
	869	No detectable change			
	870	No detectable change	Loss of tissue	No detectable change	No detectable change
	874	Loss of tissue: fish biting	Tissue growth into previously bare areas	No detectable change	
	875	No detectable change	No detectable change	No detectable change	
	876	No detectable change	No detectable change		
	877	No detectable change	No detectable change; coral paling	No detectable change	
	878	No detectable change	No detectable change	No detectable change	
	879	Tissue growth	No detectable change	No detectable change	
	NT3	No detectable change	Small loss of tissue	No detectable change	

4.4. REPETITIVE QUADRAT DISCUSSION

4.4.1. Study Site Repetitive Quadrats

Repetitive quadrats were analyzed for percent cover of benthic components, including coral species, sponge, macroalgae, CTB, and to identify coral health indicators (bleaching, paling, concentrated fish biting, isolated fish biting, and disease) in 2009 and 2010. Higher coral cover estimates (~72%) were obtained from the repetitive quadrats in comparison to the random transects (~57%) at both the EFGB and WFGB. Higher percent coral cover in repetitive quadrats relative to random transects has also been documented in previous reports (Dokken et al. 2003; Precht et al. 2006, 2008b; Zimmer et al. 2010). The most likely reason for this difference is that repetitive quadrat stations were not installed in random locations, but were originally selected as premium monitoring sites with high coral cover (large coral colonies). They were not intended to be representative of average benthic cover.

Figure 4.4.1 shows one typical repetitive photostation (number 761) from the EFGB in a time series from 2006 to 2010. Like many stations, the coral community appears to be stable and in good health during all years. Though some colonies may appear somewhat paler in certain years (e.g., note large *Montastraea cavernosa* in upper right corner in 2010), there is no significant tissue loss evident on any colonies.

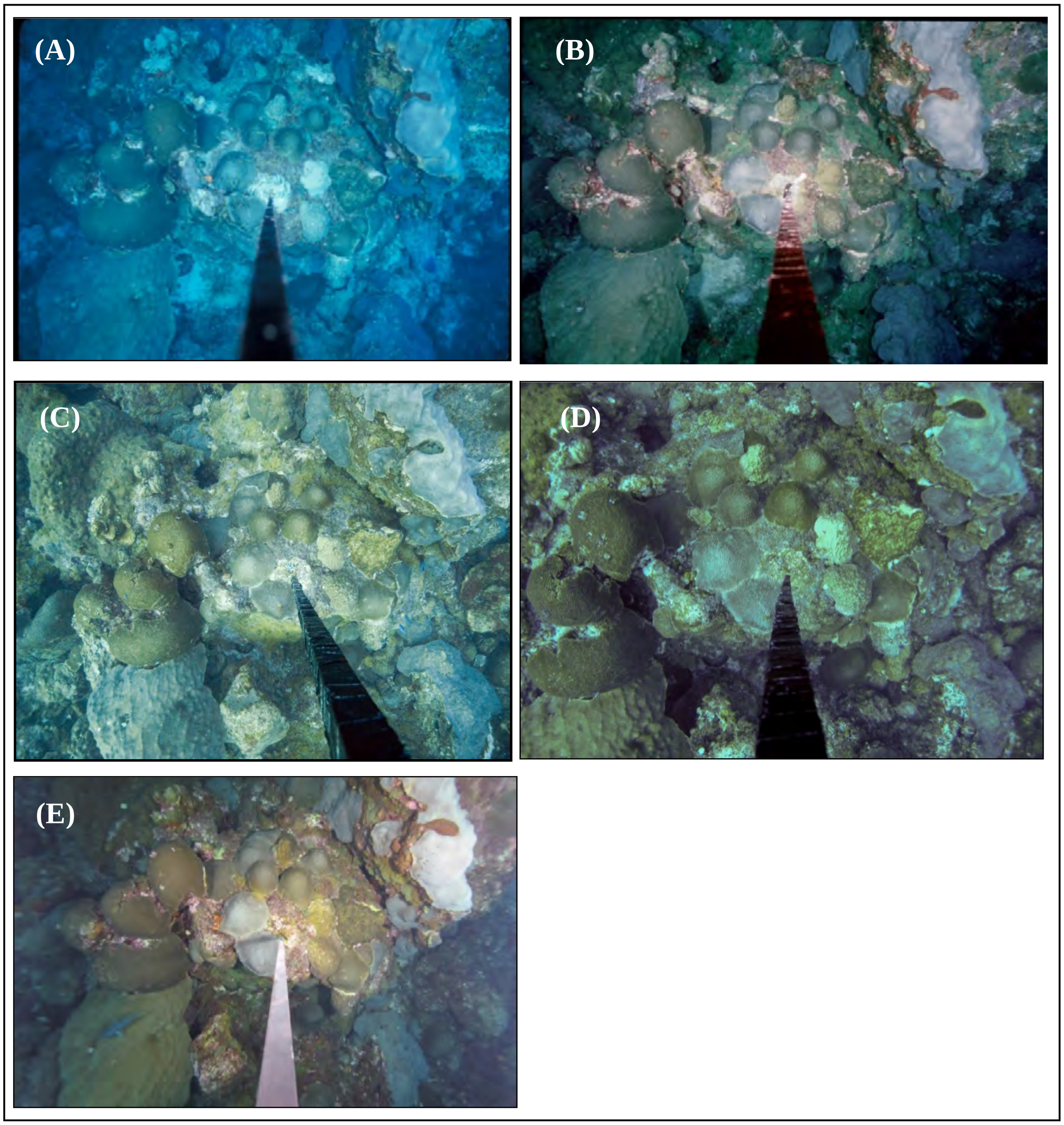


Figure 4.4.1. Repetitive photostation 761 from the EFGB in a time series from 2006 to 2010, showing a healthy and stable coral community. (A) 2006; (B) 2007; (C) 2008; (D) 2009; (E) 2010 (NOAA/FGBNMS).

Species composition at repetitive stations was similar to that in the random transects, with the dominant corals being *Montastraea annularis* species complex, *Diploria strigosa*, *Porites astreoides*, and *M. cavernosa*. The *M. annularis* species complex had higher cover estimates in the repetitive quadrats (EFGB average from 2009 and 2010: 49.03%; WFGB average for the same period: 47.03%) than in the random transects (EFGB average from 2009 and 2010: 31.71%; WFGB average for the same time period: 36.62%). The percent cover of *Porites astreoides* and *M. cavernosa* in the repetitive quadrats were roughly equivalent to the percent cover in the random quadrats.

Coral disease was absent from analyzed quadrats at both banks in 2009 and 2010. This may signify a decline in disease within the study areas from past monitoring efforts, when low levels of disease were observed (Dokken et al. 2003). Paling and bleaching were also rare, with the highest levels seen at the WFGB in 2010 (bleached coral 1.9% and paling coral 2.8%). Concentrated fish biting and isolated fish biting were similarly rare at each bank, ranging from 0.0 to 0.03% in all years.

4.4.2. Deep Station Quadrats

At the EFGB, nine deep stations located at 32–40 m depths (105–131 ft) were established in April of 2003 to monitor the deeper benthic coral community. The coral cover was high in the deep station quadrats, averaging 82% in 2009 and 2010. This amount of coral cover was similar to previous monitoring periods. In 2003, the average deep station coral cover was estimated at 76.5%. Between 2004 and 2008, it averaged 72–86% (Figure 4.4.2).

The coral community observed in the deep station quadrat photographs appears to be both healthy and stable from 2003 to 2010, with consistent percent cover above 70%.

Higher percent coral cover (~82%) in the deep station quadrats relative to random transects has also been documented in previous reports (Dokken et al. 2003; Precht et al. 2006, 2008b; Zimmer et al. 2010). As with the shallower repetitive stations, the most likely reason for this difference is that the deep stations were not installed in random locations, but were selected as premium monitoring sites with high coral cover in that depth range. The deep stations were dominated by *Montastraea annularis* species complex. *M. cavernosa* was the second-most dominant coral species, unlike the shallower study sites. Lateral growth of colonies of *Montastraea annularis* species complex was variable from year to year. Low sample sizes limited statistical power, however, making it difficult to draw firm conclusions.

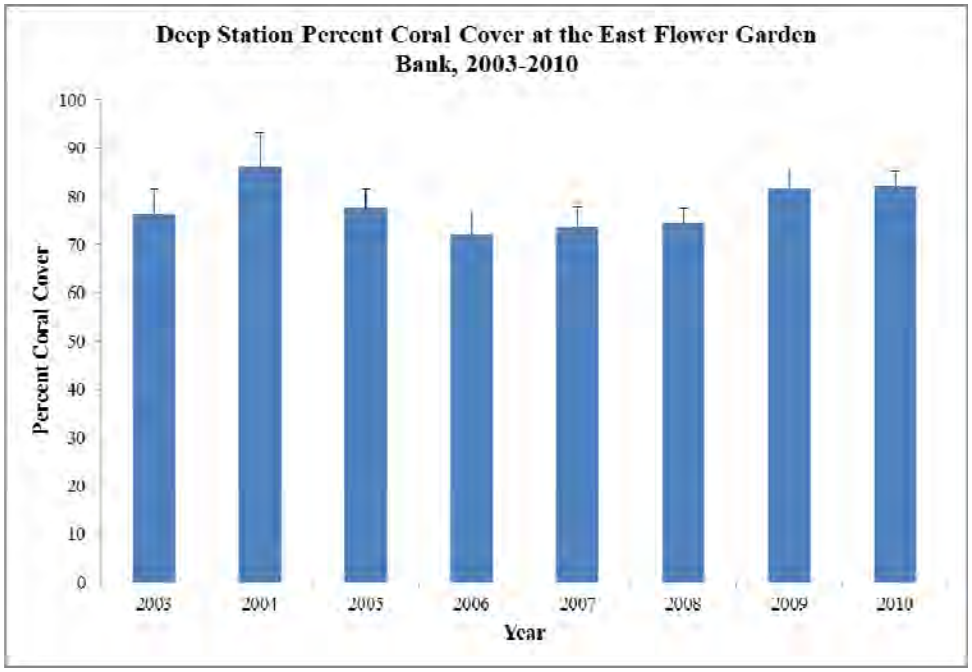
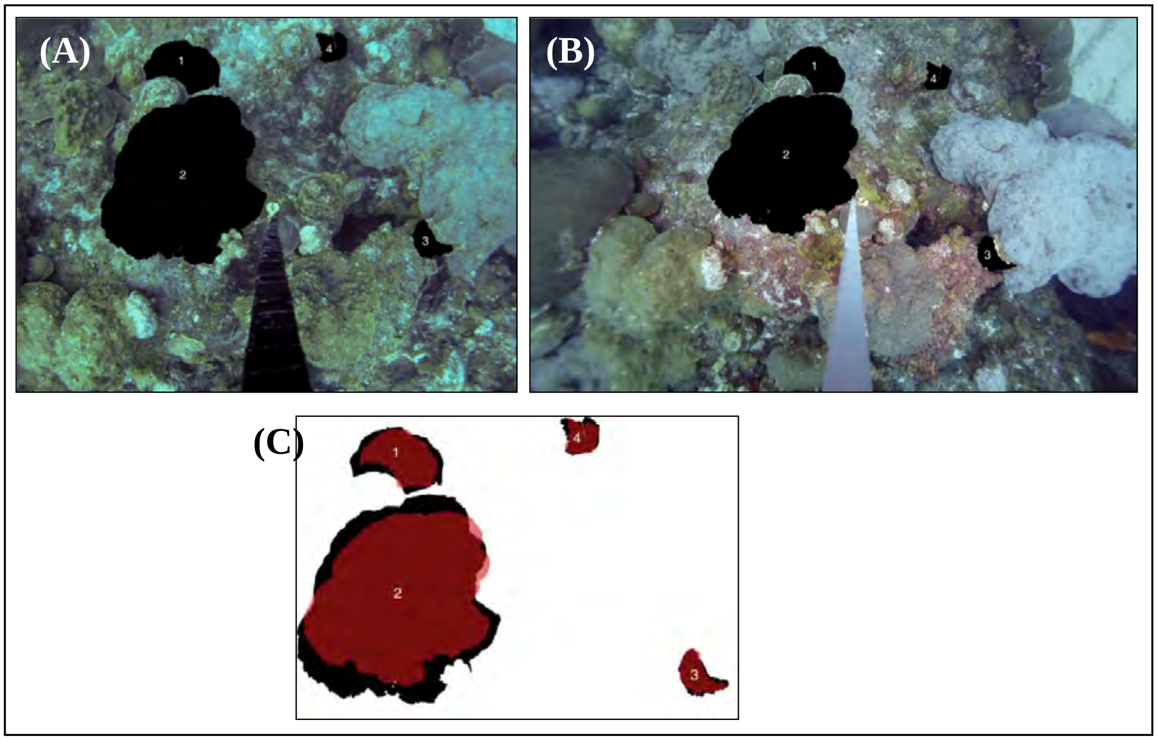


Figure 4.4.2. Deep station coral cover (+ SE) from 2003 to 2010, averaging above 70% at the EFGB.

4.4.3. Planimetry

Visual and planimetric analysis at repetitive stations generally revealed both small areas of living tissue loss and small areas of growth. Coral disease and coral bleaching were not apparent during the sampling period. Areas of paling were seen in a small percentage of corals. Areas of tissue loss were associated with fish biting and algae growth, though it is not clear whether algae competition caused coral mortality or was a result of bare substrate becoming available as a consequence of the coral tissue loss.

Attempts to measure tissue growth and tissue loss in 2009 and 2010 were complicated by a change in methods employed. Visual assessments of areas with measured changes suggested that estimates were not accurate. The differences are thought to have arisen from using a different framer, lens and camera in subsequent years. In 2009, a Nikon CoolPix P5000 digital camera was used; in 2010, a Canon PowerShot G11 was used. The Canon G11 was used in conjunction with a wide-angle dome port, in order to achieve the targeted 8 m^2 image size. While the image area was achieved, barrel distortion was observed near the edges of the images. Furthermore, because the angle of acceptance of the lenses was different, the cameras had to be located at different heights above the bottom to achieve the same sample area. The distortion was corrected in Adobe Photoshop®; but the fact that corals were photographed from slightly different angles in subsequent years could not be corrected. Therefore, it was not possible to eliminate all the error in areal measurement of coral colonies (Figure 4.4.3).



Note the overlay distortion and height differential (C) resulting from different camera outfits from each year. Camera outfit from 2010 resulted in large images, and after image correction, traced coral colonies appeared to have exhibited areal regression, thus skewing the analysis (NOAA/FGBNMS).

Figure 4.4.3. Coral colonies from repetitive quadrat station 005 at the EFGB outlined for planimetric analysis from 2009 (A) and 2010 (B) for a combined overlay (C).

Because a reliable scale in each picture was not defined before photographing coral colonies at each repetitive station, images could not be scaled to adjust for differences in area photographed in the two years. Even though the T-frame pole is in each picture, the base of the pole itself is too small to be a reliable scale for the areal measurements.

To eliminate difficulties in future monitoring analyses, FGBNMS staff will use the same camera outfit in sequential years as long as possible. The staff at the FGBNMS has also researched a more suitable camera outfit that covers a large enough image area and has a lesser degree of image distortion. A fixed scale will also be added to camera T-frames in the future to aid in planimetric image analysis.

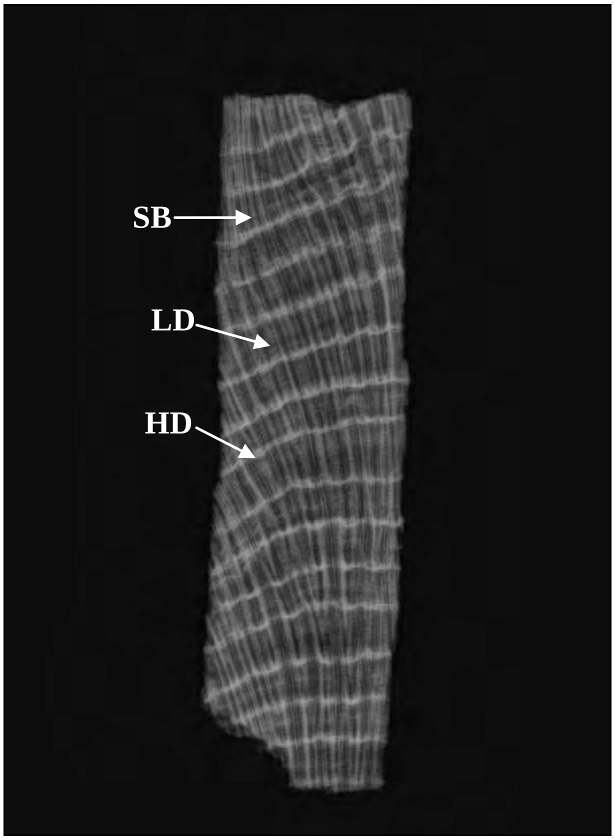
CHAPTER 5.0: SCLEROCHRONOLOGY

5.1. SCLEROCHRONOLOGY METHODOLOGICAL RATIONALE

Sclerochronology allows the determination of coral growth rates through the measurement of the accretionary growth bands deposited by corals in their calcium carbonate skeletons. One commonly measured coral growth parameter is accretionary growth. The skeletons of many corals, including *Montastraea* species, contain a consistent sequence of high- and low-density bands, comparable to tree rings. As shown in Figure 5.1.1., annual growth is represented by each couplet of adjacent high- and low-density bands. Thus, the rate of skeletal growth can be estimated by measuring the combined width of two adjacent growth bands along the length of a corallite. The skeletons of a long-lived corals therefore record the histories of coral growth, and it is possible to examine how current rates compare with those of the past. Skeletal density and mass growth are additional parameters that may be obtained using image analysis densitometry (e.g., Dodge and Kohler 1984), though these measures were not used in this study.

Although the method of counting seasonal density bands within a coral skeleton has been used for some time (Knutson et al. 1972; Buddemeier et al. 1974), there still remains some uncertainty as to the exact cause of the density variations. In the case of *Montastraea* species living in the Gulf of Mexico and Caribbean Sea, it is generally believed that annual low-density bands are produced during much of the year when favorable growth conditions exist, and annual high-density bands are produced in the summer when suboptimal growth conditions occur and the coral is putting more energy toward sexual reproduction and less into calcification. Variations in several physical environmental factors are known to influence coral skeletal density: (1) light (e.g., Macintyre and Smith 1974; Knutson et al. 1972; Wellington and Glynn 1983); (2) temperature (e.g., Highsmith 1979; Hudson et al. 1976); and (3) suspended sediment (e.g., Dodge et al. 1974; Brown and Howard 1985). Salinity and water agitation may also exert some control. Other factors that influence the metabolism of the coral may be reflected in skeletal growth, including nutrient availability and reproductive activity (Wellington and Glynn 1983; Szmant and Gassman 1990). The roles played by symbiotic zooxanthellae in influencing calcification, and endolithic algae in modifying density patterns, and the effects of boring organisms, are further complications.

Lack of high-density summer band deposition, or the occurrence of high-density winter stress bands may correspond to times during the year when significant coral bleaching or other stresses exist, including cold-air outbreaks, pulses of freshwater influx from rivers, concentrated parrotfish biting, and damselfish territory effects (Wells 1963; Buddemeier et al. 1974; Dodge 1975, 1980; Hudson et al. 1976, 1989; Kaufman 1977; Highsmith 1979; Hudson 1981a, b; Smith et al. 1989; Leder et al. 1991; Fitt et al. 1993; Heiss and Dullo 1995; Insalco 1996). Care must be taken to differentiate between normal, annual bands and other bands produced by stressful non-cyclic environmental fluctuations (Graus and Macintyre 1982; Leder et al.1991).



LD=low-density growth band, HD=high-density growth band, and SB=stress band

Figure 5.1.1. X-ray of Montastraea faveolata showing skeletal banding (NOAA/FGBNMS).

5.1.1. Why Montastraea faveolata?

The determination of coral growth rate has been identified as one of the best quantitative measures of assessing coral stress due to disturbance, because this parameter integrates a variety of physiological processes (Brown and Howard 1985). It is also widely accepted that coral growth rates may be inherently variable for a single species within a reef zone and even within individual colonies (Buddemeier and Kinzie 1976). Gladfelter et al. (1978) described some species as “conservative” in their growth. Specifically, they argued that the *Montastraea annularis* species complex shows relatively little response in growth rate to varying environmental conditions compared to other species. However, studies have shown significant suppression of *M. faveolata* growth may occur if a coral is disturbed, for example, by short-term exposure to high concentrations of drilling mud (Hudson and Robbin 1980) or by changes in environmental parameters when a coral is transferred from an offshore location to an inshore site (Hudson 1981b).

A significant feature revealed by X-radiography is the presence of high-density skeletal deposits or “stress” bands, which have been observed in sections of *Montastraea annularis* during periods of rapid chilling and mixing of shallow inshore waters (Hudson et al. 1976; Hudson 1977, 1981a; Shinn et al. 1989) and during periods of increased sea surface temperatures and coral bleaching (Leder et al. 1991).

Previous research on sclerochronology in the *Montastraea annularis* species complex has been extensive (Dustan 1975; Hudson et al. 1976; Emiliani et al. 1978; Foster 1980; Hudson 1981a, 1981b; Graus and Macintyre 1982; Dodge and Lang 1983; Dodge and Brass 1984; Leder et al. 1991; Slowey and Crowley 1995). It has been shown that accelerated growth in *Montastraea* occurs seasonally during cooler periods (Leder et al. 1991). In Belize, Highsmith (1979) noted that, when compared with *Montastraea cavernosa* and *Porites astreoides* from the same locality, high- density bands of *Montastraea annularis* appeared to be deposited only for short periods of time, whereas the low-density bands were generally produced for a greater part of the year.

5.2. SCLEROCHRONOLOGY FIELD AND LABORATORY METHODS

Random *Montastraea faveolata* core samples from each quadrant at the Flower Garden Banks are usually collected every two years. Originally, the cores for the monitoring period were scheduled to be collected in 2009, but equipment was not available that year. The cores were taken at the EFGB in August of 2010 and at the WFGB in November of 2010. At each bank, four cores were extracted from *Montastraea faveolata* colonies, for a total of eight cores. A pneumatic drill, fitted with a diamond tipped 35 mm (1.38 in) lapidary bit, was used to extract short cores of skeletal material from the apex of robust *M. faveolata* colonies. Corals were sampled at their apex and cores were drilled down the main growth axis. They were collected from the apex because growth rate is known to vary across the surface of an individual coral colony and it is at the apex where the maximum rate typically occurs. The longitudinal axis of each core was also oriented as closely as possible to the direction that the corallites appeared to grow. Cores were 35 mm (1.38 in) in diameter and from 54 to 135 mm (2.13 to 5.31 in) long, spanning six to nineteen years of growth. Short cores spanning ten or more years of growth were recovered because they could be collected quickly and easily. The hole left from core extraction was filled with pre-drilled coral skeleton plugs and coral rubble (obtained from coral cores extracted during mooring drilling), and LiquidRoc 500® to prevent subsequent mortality and bioerosion of the sampled colony. All eight coral cores were transferred to the laboratory of Dr. Niall Slowey, Department of Oceanography at Texas A&M University, for processing and analysis.

Cores from the field were placed in containers with 95% ethanol solution and kept refrigerated until they were shipped in coolers to Texas A&M University for analysis. In the laboratory, a custom rock saw with dual diamond blades was used to cut 8-mm-thick slabs of coral skeletal material from along the longitudinal axis of each core. These slabs were washed, air dried, and then a digital X-ray system was used to collect images that revealed variations in the skeletal density and allowed annual couplets of low and high density bands, plus high-density stress bands to be identified.

Ages for the annual band couplets were assigned by counting backwards from the most recently deposited colony surface toward older skeletal material. Annual extension distances were determined by measuring the thickness of adjacent high and low density couplets by grayscale analysis of the digital X-radiographs using CoralXDS software (Helmle et al. 2002) from Nova Southeastern University. It was presumed that one year's growth corresponds to the distance from the top of a high density band to the bottom of the adjacent low density band (i.e., the thickness of each couplet), representing the annual growth rate.

5.3. DATA PRESENTATION AND STATISTICAL ANALYSIS OF GROWTH RATES

After the annual accretionary growth rates were determined for each coral core, the means and standard errors or standard deviations were calculated for each bank and year. A Student's t-test assuming equal variances compared values between the EFGB and WFGB.

Data are also presented in this report from prior sampling efforts. In 2005, core and X-ray processing was conducted at Florida International University (Miami, Florida) and Nova Southeastern University (Dania Beach, Florida). In 2007, core and X-ray processing was conducted at the Florida Keys National Marine Sanctuary–Upper Keys Office in Key Largo, Florida.

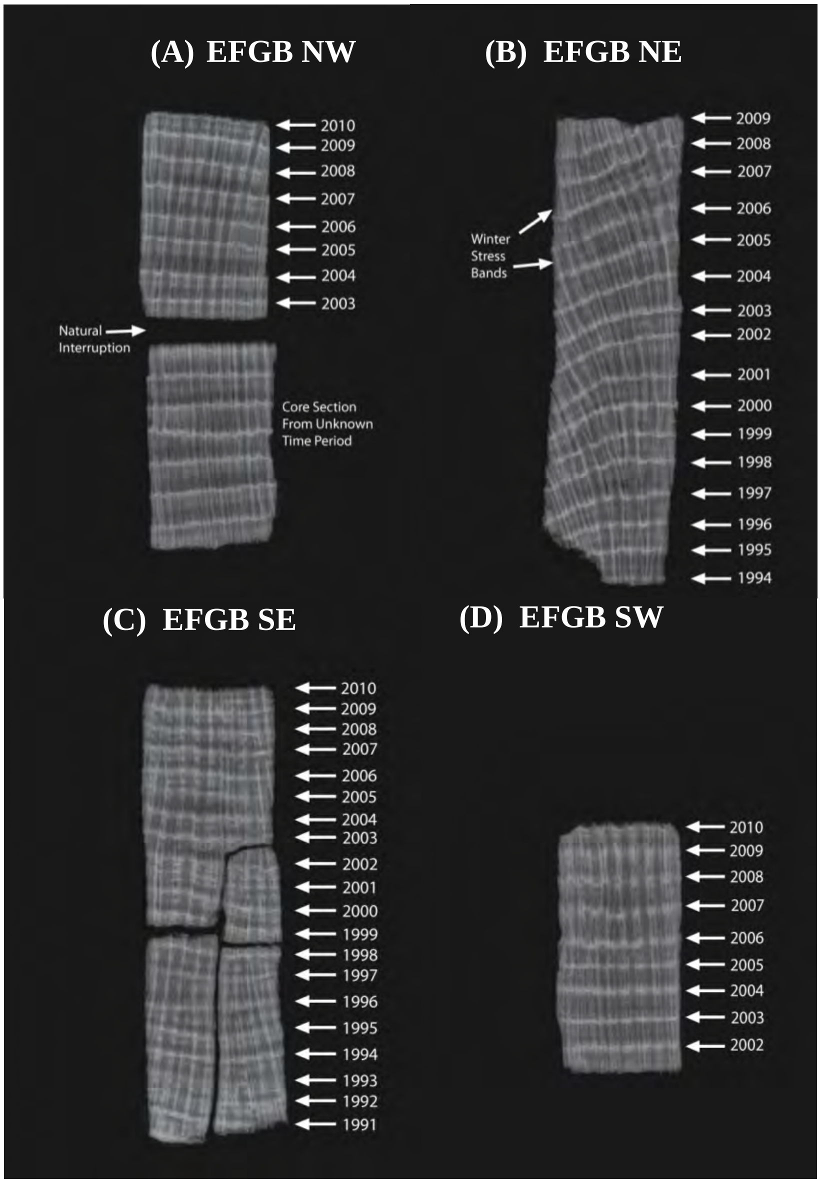
5.4. SCLEROCHRONOLOGY RESULTS

X-ray images of the slabs of skeletal material from each core revealed two types of distinct high-density bands: annual bands presumably deposited during late summer, and stress bands deposited during periods of otherwise rapid growth (Figures 5.4.1 and 5.4.2). Estimates of annual growth are shown in Table 5.4.1. Standard error values were calculated for each bank and year when comparable measurements were available. The longest time periods spanned by the coral cores were from 1991 to 2010 for the EFGB and from 1998 to 2010 for the WFGB. The core collected from the northwest quadrant at EFGB was not used for extension rate comparison due to breakage that occurred around the midpoint of that core (i.e., the core barrel caused the two segments to grind together during drilling) making it impossible to assign ages to the underlying annual bands.

The annual growth rates of *Montastraea faveolata* cores extracted in 2010 at the EFGB ranged from 3.0 mm to 7.6 mm. The mean growth for the EFGB between 1991 and 2010 was 5.5 mm/yr (Table 5.4.1). The maximum occurred between 1996 and 1997 and the minimum between 1991 and 1992 (Figure 5.4.3).

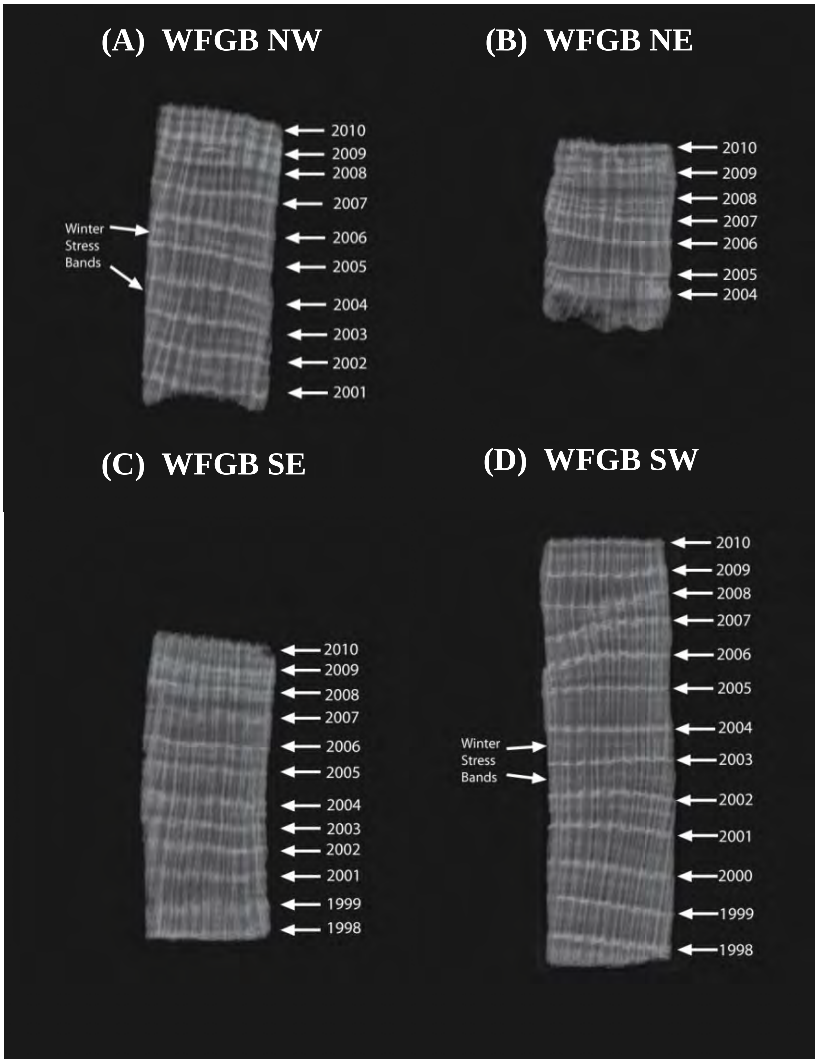
The annual growth rate of *Montastraea faveolata* at the WFGB ranged from a 3.3 mm to 9.7 mm between 1998 and 2010. The mean at the WFGB between 1998 and 2010 was 6.9 mm/yr (Table 5.4.1). The maximum growth occurred between 2000 and 2001 and the minimum between 2009 and 2010 (Figure 5.4.3).

To determine if the growth rates differed significantly between banks, a Student's t-test was performed. There was a significant difference (α=0.05, P-value=0.0011) in the growth rate between the banks when comparable years (1998 to 2010) were analyzed. There was also a significant difference (α=0.05, P-value=0.0010) when all years (1991 to 2010) were combined.



Summer high-density bands are dated. NW=northwest, NE=northeast, SE=southeast, SW=southwest.

Figure 5.4.1. X-radiographs of *Montastraea faveolata* skeletal structure in the plane of corallite growth from four quadrants in the EFGB long-term monitoring study site.



Summer high-density bands are dated. NW=northwest, NE=northeast, SE=southeast, SW=southwest.

Figure 5.4.2. X-radiographs of *Montastraea faveolata* skeletal structure in the plane of corallite growth from four quadrants in the WFGB long-term monitoring study site.

Table 5.4.1.

Estimates of Annual Growth (mm/yr) of *Montastraea Faveolata* from Cores Extracted at the EFGB and WFGB in 2010

Coral cores are designated by quadrant in each study site. NW=northwest, NE=northeast, SE=southeast, SW=southwest, *SE*=Standard Error

Year	**East Flower Garden Bank**					
	NW	**NE**	**SE**	**SW**	**Mean**	***SE***
2009–2010			4.3	5.4	**4.9**	0.6
2008–2009		6.0	4.2	6.7	**5.6**	0.7
2007–2008		5.1	4.3	6.2	**5.2**	0.6
2006–2007		6.0	4.8	6.8	**5.9**	0.6
2005–2004		7.6	4.2	5.2	**5.7**	1.0
2004–2005		6.9	5.8	5.4	**6.0**	0.4
2003–2004		6.3	4.7	6.3	**5.8**	0.5
2002–2003		4.8	4.9	5.7	**5.1**	0.3
2001–2002		7.1	3.3		**5.2**	1.9
2000–2001		6.1	4.9		**5.5**	0.6
1999–2000		6.9	4.5		**5.7**	1.2
1998–1999		5.7			**5.7**	
1997–1998		7.3	5.7		**6.5**	0.8
1996–1997		6.6	7.0		**6.8**	0.2
1995–1996		6.1	5.3		**5.7**	0.4
1994–1995		6.6	5.3		**6.0**	0.7
1993–1994			4.7		**4.7**	
1992–1993			4.9		**4.9**	
1991–1992			3.0		**3.0**	
Mean EFGB Growth Rate (mm)					**5.5**	**0.7**

West Flower Garden Bank						
Year	**NW**	**NE**	**SE**	**SW**	**Mean**	***SE***
2009–2010	5.1	4.7	5.5	7.3	**5.7**	0.6
2008–2009	5.6	7.1	3.9	7.3	**6.0**	0.8
2007–2008	6.7	3.3	6.1	6.9	**5.8**	0.8
2006–2007	6.9	5.1	7.2	8.0	**6.8**	0.6
2005–2004	6.5	7.2	5.5	7.8	**6.8**	0.5
2004–2005	7.3	5.3	7.3	9.7	**7.4**	0.9
2003–2004	7.1		5.8	7.0	**6.6**	0.4
2002–2003	7.1		4.6	7.3	**6.3**	0.9
2001–2002	8.0		6.1	7.5	**7.2**	0.6
2000–2001			8.8	10.1	**9.5**	0.6
1999–2000			4.9	8.2	**6.6**	1.7
1998–1999				8.4	**8.4**	
Mean WFGB Growth Rate (mm)					**6.9**	**0.8**

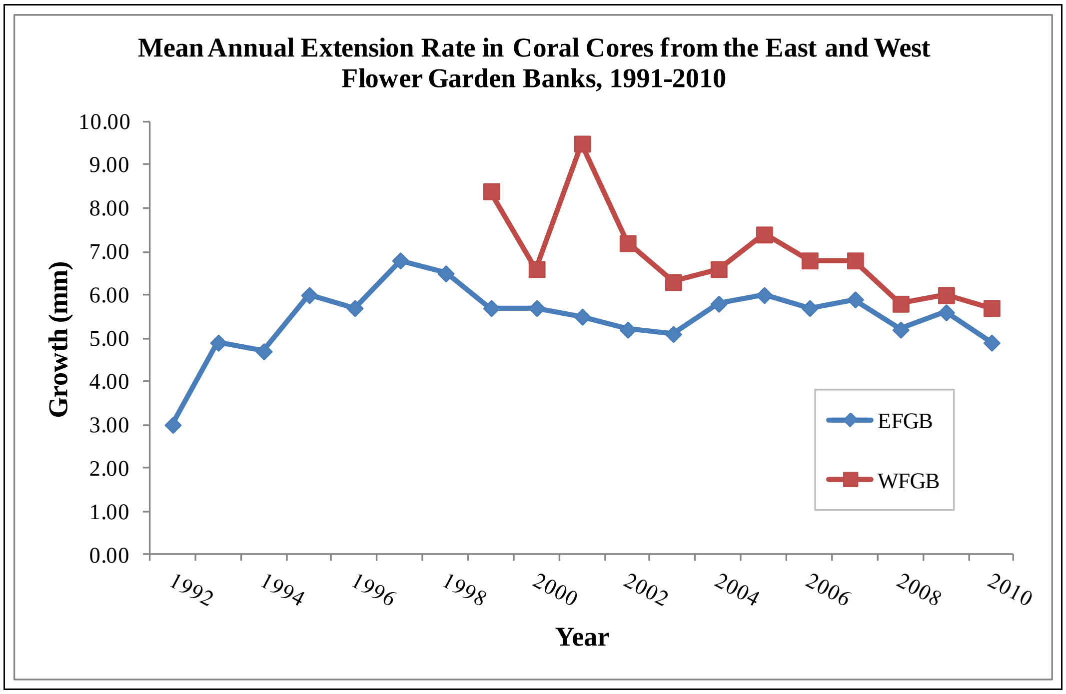


Figure 5.4.3. Mean annual growth rates in cores collected in 2010 at the EFGB and WFGB.

5.5. SCLEROCHRONOLOGY DISCUSSION

A variety of factors can affect coral growth rate including depth, salinity, temperature, light, genetic factors, and relative position on the colony (Knutson et al. 1972; Bak 1974; Weber and White 1977; Highsmith 1979; Hudson 1981a; Hudson et al. 1989; Smith et al. 1989).

Accretionary rates of *Montastraea annularis* documented over a wide geographic range throughout the Caribbean vary from 3.0 to 12.0 mm/yr (Weber and White 1977). Growth rates have been shown to vary with depth, with faster growth rates generally occurring in shallower water (Weber and White 1977). Hudson (1981a) reported growth rates of *M. annularis* in the Florida Keys to be 6.3 mm/yr on offshore reefs and 8.2 mm/yr on mid-shelf reefs from 1928 to 1978. Hudson and Robbin (1980) and Deslarzes (1992) reported annual growth rates for 16 colonies of *M. annularis* at the FGB. The mean was 7.9 mm/yr from 1886 to 1907, 8.8 mm/yr from 1907 to 1957, 7.0 mm/yr from 1957 to 1988, and 9.0 mm/yr during 1988–89 (the last year for which they had data).

Dokken et al. (2001) reported a lower growth rate for 1985–1999, with an average of 6.80 mm/yr at the EFGB and 5.13 mm/yr at the WFGB. The shorter sampling period was offered as a possible explanation for the observed differences. Alternative explanations are that the cores analyzed by Dokken et al. were not taken from the apex of the coral head, were taken from smaller coral heads than those analyzed by Hudson and Robbin (1980) and Deslarzes (1992), and/or that *M. franksi* may have been mistakenly sampled instead of *M. faveolata*. Each possibility would result in lower estimates that are not readily comparable with the Hudson and Robbin (1980) and Deslarzes (1992) data.

During the 2009–2010 sampling period, *Montastraea faveolata* growth ranged from 3.0 to 7.6 mm/yr at the EFGB and 3.3–9.7 mm/yr at the WFGB. These results were similar to the growth rates reported by Zimmer et al. (2010) for the 2004–2008 long-term monitoring reporting periods, but differed slightly from the growth rates reported by Precht et al. (2006) and the past work by Dokken et al. (2003), who reported a wider range of growth rates at the EFGB and WFGB. Growth rates for *M. faveolata* at the WFGB, and less so at the EFGB, continued to be in the middle to upper range of FGB growth rates as recorded by Hudson and Robbin (1980).

When compared to the past three coring events (2003, 2005, and 2007), the 2010 data are not significantly different ($\alpha=0.05$, P-value=0.067) with respect to mean growth rates (Figure 5.5.1). However, the range in annual growth decreased in 2010 for cores from the EFGB and for cores from the WFGB (with the exception of cores from the year 2005).

In long-term growth studies of *Montastraea faveolata* corals at the Flower Garden Banks, Hudson and Robbin (1980) and Deslarzes (1992) observed that a late 1950s growth decline is a prominent feature of the records. Studies first hypothesized this decline could be caused by lower light levels due to bank subsidence resulting from salt dome dissolution (Rezak and Bright 1981), or local variations in water temperature or outflow from the Atchafalaya River (Dodge and Lang 1983; Szmant-Froelich 1984) with a positive correlation between and winter/spring temperature and growth, and a negative correlation between Atchafalaya River discharge and growth. The analysis by Slowey and Crowley (1995) supported the temperature explanation and fit it into a large scale climatic context. They compared meteorologic and coral growth records and found that during the past century changes in coral growth at the FGB correspond to changes in the winter climate of the Gulf of Mexico/southeastern USA. Slowey and Crowley (1995) found that recent decadal scale variability in both coral growth and regional wintertime climate are closely linked to changes to the orientation of the mid-latitude atmospheric jet stream over North America. When the jet stream has a more north-south orientation, wintertime temperatures in the Gulf of Mexico/southeastern USA are colder and the corals exhibit slower growth and possess more winter stress bands.

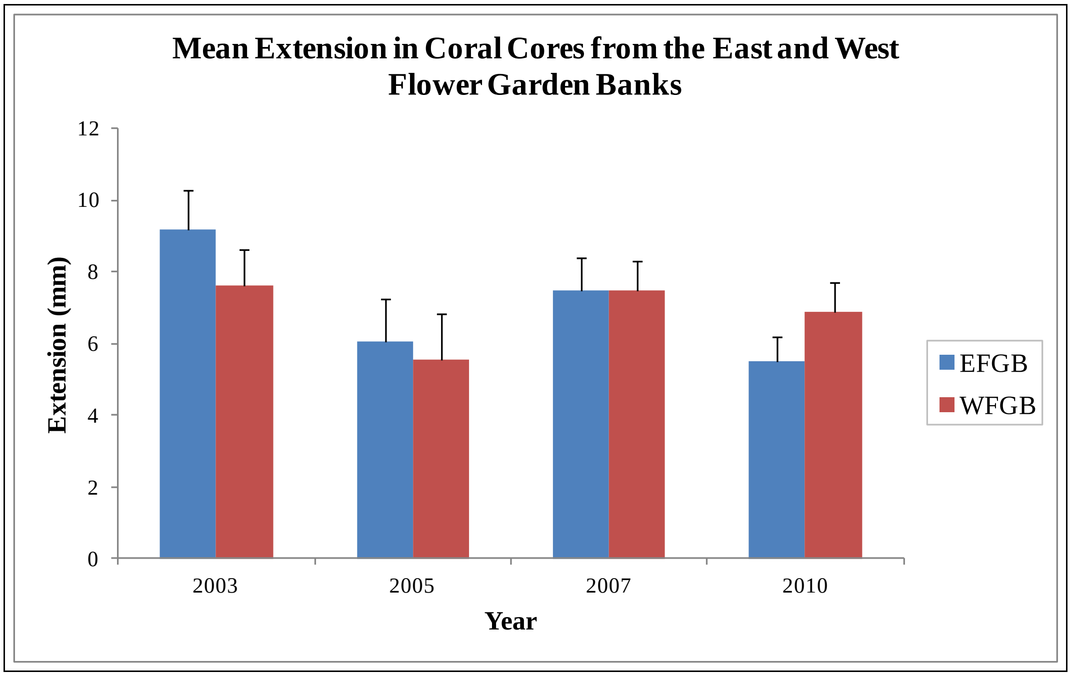


Figure 5.5.1. Mean annual growth rates (+SE) based on analysis of *Montastraea faveolata* 2003, 2005, 2007, and 2010 cores from the EFGB and WFGB.

Variations in the orientation of the jet stream and wintertime climate are controlled by the Pacific North American Pattern of wintertime climate variability, with a north-south jet stream orientation being associated with the positive phase of the pattern (Wallace and Gutzler 1981). Significant interdecadal variations in the Pacific North American Pattern occur. Studies indicate that the pattern is among the dominant modes of extratropical climate variability in the Northern Hemisphere (Simmons et al. 1983; Wallace et al. 1993).

Hudson (1981a, 1984) observed that *Montastraea faveolata* corals within the Florida Keys National Marine Sanctuary show a decline in growth rates and deposited abundant winter stress bands during the late 1950's and early 1960's. Fluctuations in river discharge cannot account for changes in Florida Keys coral growth. The similarity in temporal variations in extension rate changes and stress banding displayed by both Flower Garden Banks and Florida Keys corals supports the contention that coral growth in both locations is most likely impacted by regional changes of wintertime climate (Slowey and Crowley 1995).

In the summer of 2010, the FGB experienced an unusual warming of the water column and comparatively high rates of coral bleaching, which were reflected in the data at WFGB. As described in the random transect data, approximately 7% of the corals at the WFGB were bleached and 11% were paling. The *M. annularis* species complex was the species most impacted by bleaching and paling. The 2010 coral core collection occurred during this bleaching event; the coral cores did not indicate a large drop in growth during the 2009–2010 monitoring period. However, cores collected for the next monitoring period may display reduced growth rates due to the 2010 bleaching event.

CHAPTER 6.0: LATERAL GROWTH

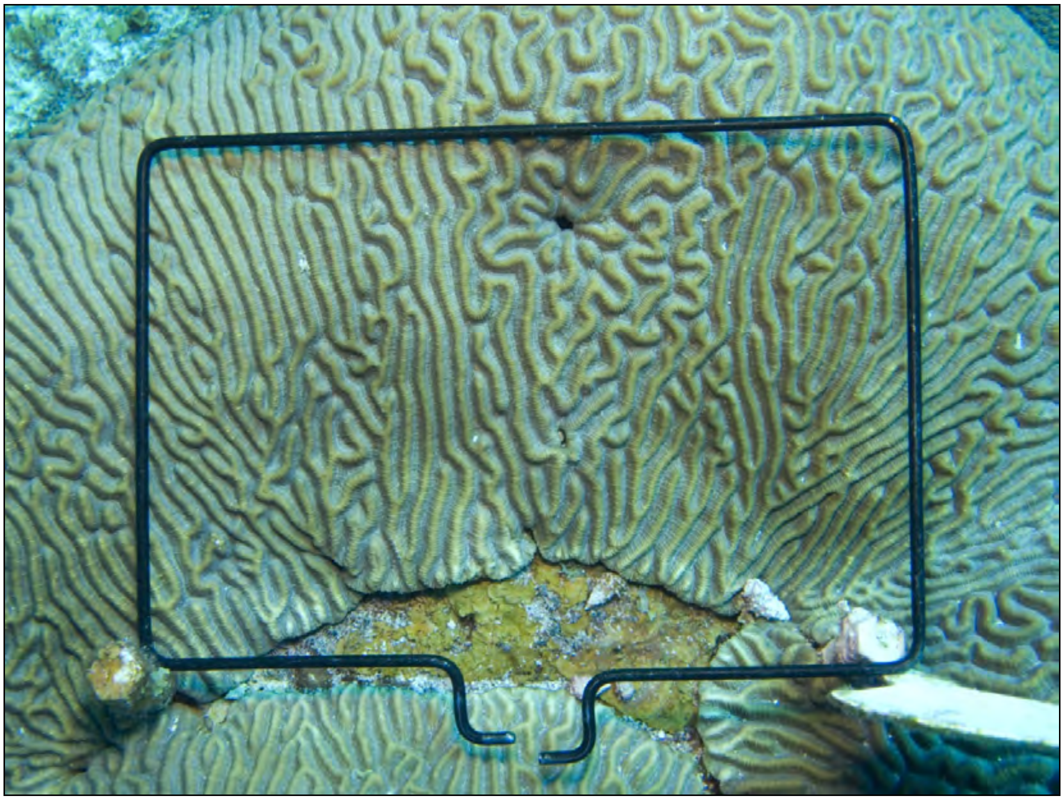
6.1. LATERAL GROWTH METHODOLOGICAL RATIONALE

Diploria strigosa is the second largest contributor to coral cover at the FGB after the *Montastraea annularis* species complex (Bright et al. 1984; USDOI, MMS 1998; Dokken et al. 2003; Gittings et al. 1992; Precht et al. 2006; Precht et al. 2008b; Zimmer et al. 2010). The lateral margins of selected *D. strigosa* colonies were monitored and photographed annually to detect any incipient changes over time and space. *D. strigosa* is more suitable than other coral species due to the conspicuous patterns and grooves that, when photographed, can be matched when repetitive annual photographs are overlaid.

6.2. LATERAL GROWTH FIELD AND LABORATORY METHODS

Sixty lateral growth stations, located on the margins of *Diploria strigosa* colonies, were maintained at each bank (Figure 6.2.1). Divers were equipped with a camera, a close-up kit (close-up framer), and strobe. In the 2009 field season, a Nikonos V 35 mm underwater film camera with a Nikkor 28 mm lens was used initially at the EFGB for the first 35 station images. The camera aperture was set at f/22, focal distance at infinity, and TTL strobe control. A 13.3 x 19.7 cm image was captured. However, due to mechanical failure of the Nikonos camera, an alternate camera system was used for the remainder of the 2009 data collection. A Canon G6 digital camera with Ikelite housing and Ikelite digital strobe DS125 was used to capture the remaining lateral growth station images for 2009. The camera was set at auto exposure, ISO 100, on macro and autofocus settings, and the strobe was set to TTL. This created an image larger than the close up kit framer, which was later cropped using Photoshop CS5® to the match sizes. For the 2010 field season, a replacement digital camera system was evaluated with the close-up kit (close-up framer), and strobe. A Canon Power Shot G11 in Fisheye Fix housing with a standard port was used. The camera was set at auto exposure, ISO 200, on macro and autofocus settings, and strobe set to TTL. The framer was placed on corner pins at each station, ensuring a repeated image of the station. Some stations were missing identification tags. Those stations that did have tags were photographed with the tag in the frame. For stations without tags, the current photographs were matched with past photographs using the ridge patterns of the *Diploria strigosa* colonies.

In 2009, 41 and 40 colonies of *Diploria strigosa* were photographed on the EFGB and WFGB, respectively. In 2010, 29 and 34 lateral growth stations were photographed at the EFGB and WFGB, respectively. Of the photographs taken, five matching pairs were comparable from 2009 and 2010 for the EFGB, and nine matching pairs were comparable for the WFGB. Several factors contribute to the large discrepancy in the number of photographs collected versus the number of photographs that are useful during analysis. These factors include: (1) photographs are not taken in the same position or orientation each year due to missing bolts, photographer error, and changes in the rugosity of some colonies and (2) some stations no longer have margins to measure in a photograph due to colony growth or death. It is also important to note that more than 60 lateral growth stations are located at each bank. In the past, stations have been abandoned and rehabilitated and new stations have also been installed. During some monitoring events, all lateral growth stations were marked for photography, both old and new, while during other monitoring cruises only the new stations were marked. Regardless of the method used to mark stations, the collection of lateral growth photographs ceased when the number of stations photographed totaled 60, or as close to 60 as possible given the time constraints at each study site. In other words, while there may have been nearly 60 stations photographed in two consecutive years, there were far fewer than 60 photo comparisons possible for the reasons listed above.

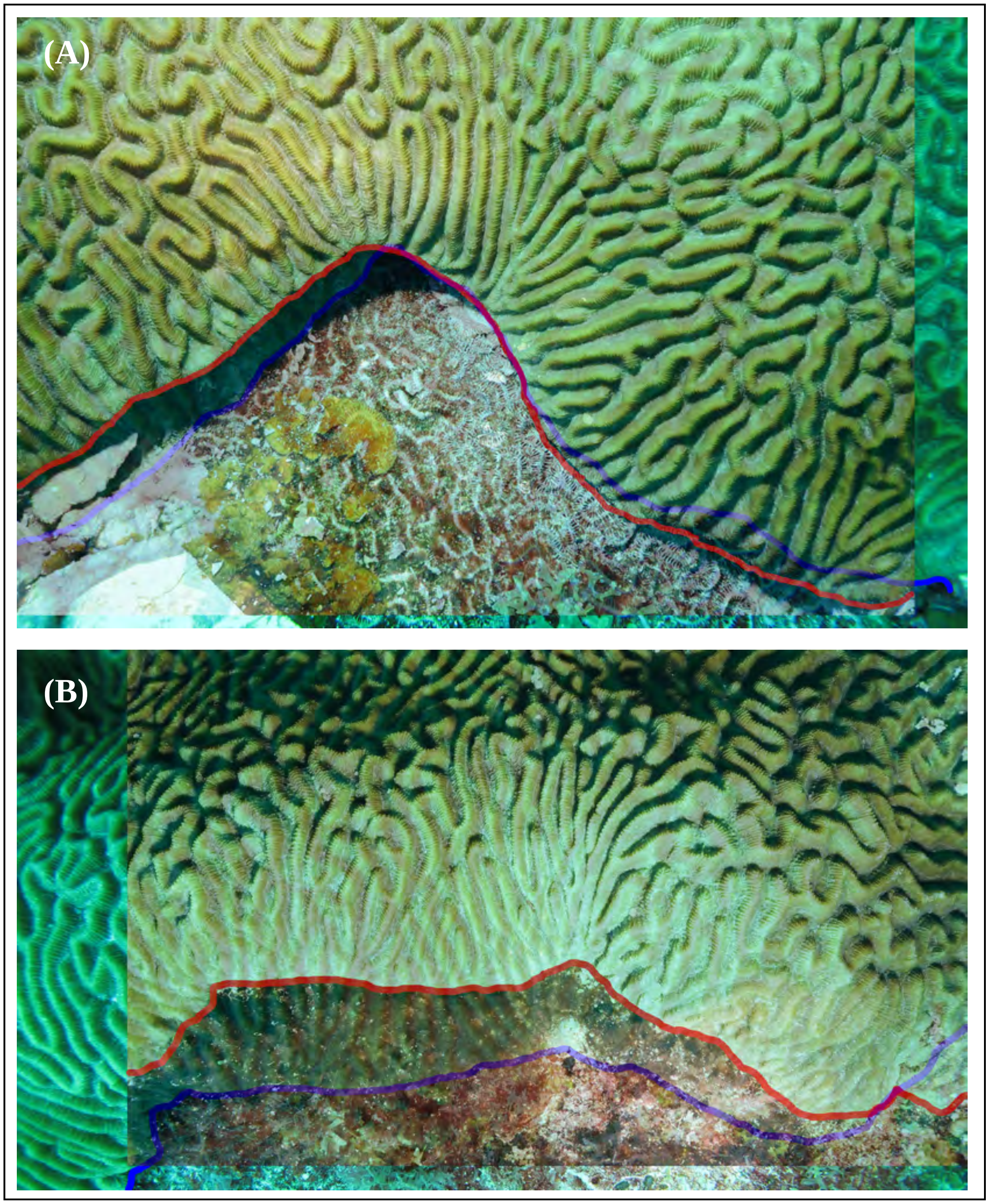


Note overgrowth of marker bolts by coral and the approach of the advancing edge of the coral to the station boundary, even extending beyond it in some places.

Figure 6.2.1. Lateral growth station #52 on a *Diploria strigosa* colony with close-up framer at the EFGB (NOAA/FGBNMS).

6.2.1. Image Analysis for Lateral Growth

Images corresponding to a specific lateral growth station were compared between consecutive years (2009 and 2010). Lateral differences in the margins of the *Diploria strigosa* colonies were evaluated by overlaying the pairs of photographs, using Photoshop CS5®, and dividing the lateral growth edge of the colony vertically into areas categorized as “growth,” “retreat,” “stable,” and “not available” (for areas that were dark, shadowed, or out of focus). Using ImageJ® (a public domain, Java-based image processing program developed at the National Institutes of Health), the entire horizontal width of the frame was set to 100 units, then the horizontal distances of growth, retreat, and stability were measured (Figure 6.2.2). These values were then combined to obtain an overall percentage of growth, retreat, and stability for each image. Successive photographs of a given colony were aligned using the colony’s ridge patterns.



The red line is the 2009 margin and the blue line is the 2010 margin. (A) growth (red line) on station #12 and (B) retreat (blue line) on station #13. Sections where lines overlap demonstrate stasis (NOAA/FGBNMS).

Figure 6.2.2. Image analysis of *Diploria strigosa* lateral growth at the EFGB.

6.3. DATA PRESENTATION AND STATISTICAL ANALYSIS FOR LATERAL GROWTH

Proportional annual changes in the lateral margin of individual *Diploria strigosa* colonies, whether positive or negative, were examined per bank per year. A percent change value was calculated for each comparable image, and each image was assigned an overall designation category of growth, retreat, or stability from 2009 to 2010. Lateral growth data was not collected during the 2008 annual monitoring cruise due to the constraints of weather; therefore, there was no comparable data from 2008 to 2009.

Growth, retreat, and stability of colony margin tissue were calculated by subtracting the linear distance for each category measured for each station for the current year from the linear distance for each category measured during the previous year. Areas of the picture that were not distinguishable during analysis were not included in the total percentage. Percent changes were calculated by determining the linear margin gained or lost and dividing by the total units of the photographed colony margin and multiplying by 100. Due to the low sample size from 2009 through 2010, a repeated measures Analysis of Variance with enough power was not possible for analysis. Therefore, these data are used for descriptive purposes only.

6.4. LATERAL GROWTH RESULTS

Proportion of marginal tissue growing, retreating, or remaining stable in lateral growth of individual colonies, whether positive or negative, were examined by site (EFGB and WFGB) and by year (2009 and 2010). Of the photographs taken in 2009 and 2010, only five were comparable for the EFGB, and nine were comparable for the WFGB.

Throughout the 2009 to 2010 monitoring period, a large number of photographs were unsuitable for analysis due to a variety of reasons, including but not limited to, photographer error, improper orientation, missing guide bolts, and no visible margins in the photo due to colony growth or death. Due to the low number of comparable photographs, no statistics were used to analyze the lateral growth rates of change. Appendix 3 contains the lateral growth data from 2009 and 2010 at the FGB.

There was a high degree of variability between progression/regression percentages among years for both the EFGB and WFGB (Table 6.4.1). At the EFGB, there was an overall increase in marginal growth from 2009 to 2010. The WFGB also showed a slight increase in *Diploria strigosa* marginal growth.

Table 6.4.1.

Lateral Growth Stations on *Diploria Strigosa* and Percent of Margin Growing, Retreating, or Remaining Stable of Coral Tissue at the EFB and WFGB from 2009 to 2010

Site	**Percent Change from 2009 to 2010**		
EFGB Station	**Growth**	**Retreat**	**Stable**
EFGB 10	6.73	59.88	33.39
EFGB 12	40.25	44.16	15.58
EFGB 13	91.50	8.50	0.00
EFGB 29	92.47	7.53	0.00
EFGB 34	51.56	48.44	84.66
WFGB Station	**Growth**	**Retreat**	**Stable**
WFGB 68	82.43	0.00	17.57
WFGB 69	100.00	0.00	0.00
WFGB 73	59.53	12.80	30.37
WFGB 94	0.00	92.58	7.42
WFGB 95	45.37	28.97	25.28
WFGB 99	79.15	15.52	5.33
WFGB 106	24.37	63.61	12.02
WFGB 118	0.00	67.63	32.37
WFGB 121	0.00	50.30	49.70

Ternary plots were produced to compare the relative amounts of progression, regression, and stasis at the lateral growth stations. These compare the relative amounts of gain, loss, or no change without regard to change along the margins. Each station provided single estimates of each measure (growth, reatreat, and stability), regardless of the number of areas of progression or regression present at the FGB.

At both the EFGB and WFGB, the proportions of marginal growth, from 2009 to 2010 were high. Greater than 50% of all the marginal length analyzed was advancing (Figures 6.4.1 and 6.4.2).

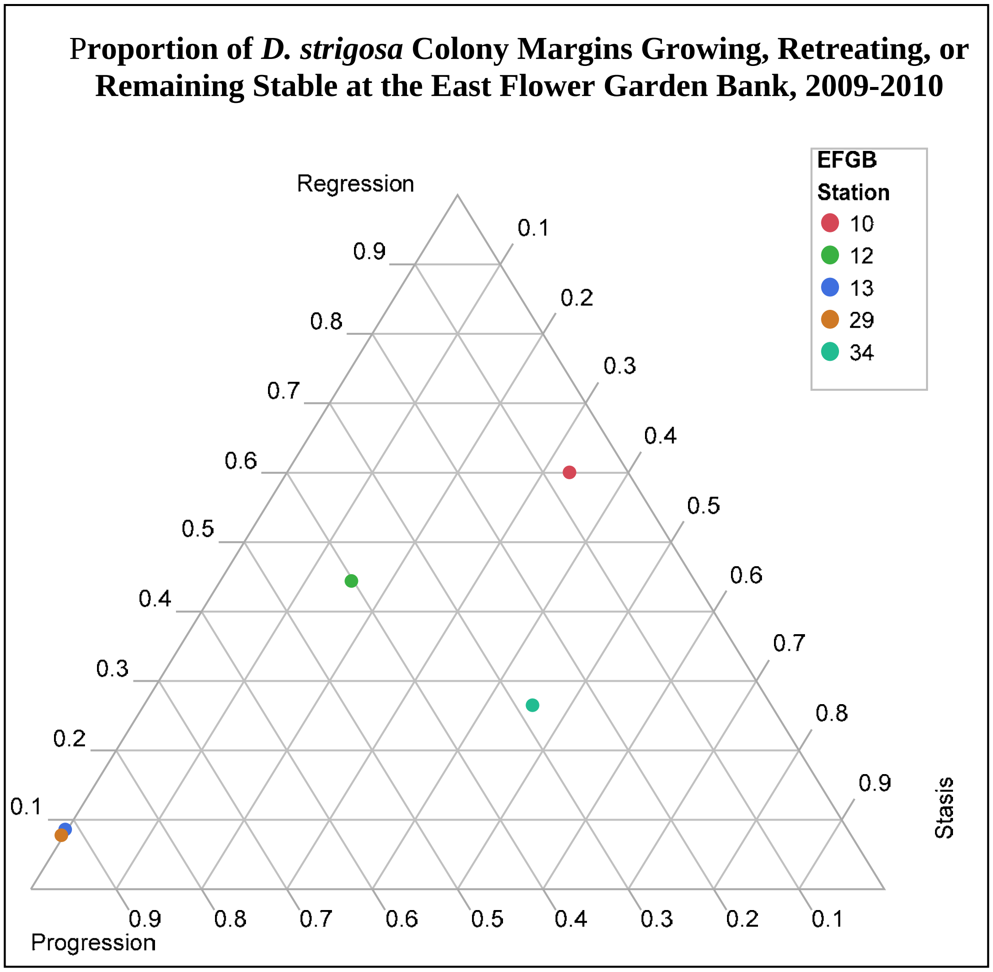


Figure 6.4.1. Ternary diagram showing the proportion of *Diploria strigosa* marginal tissue growing, retreating, or remaining stable at each station photographed at the EFGB from 2009 to 2010.

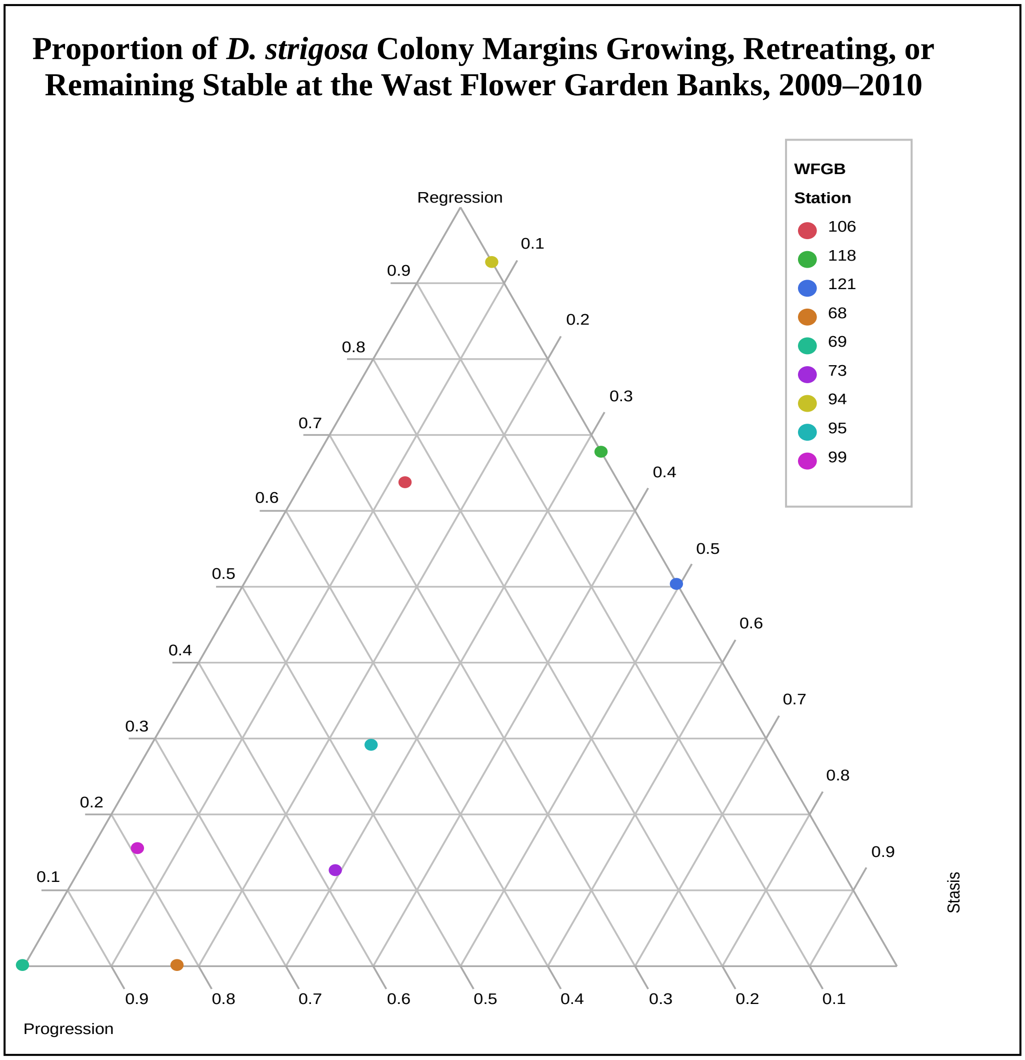


Figure 6.4.2. Ternary diagram showing the proportion of *Diploria strigosa* marginal tissue growing, retreating, or remaining stable at each station photographed at the WFGB from 2009 to 2010.

6.5. LATERAL GROWTH DISCUSSION

Net lateral growth of *Diploria strigosa* was positive during the 2009 and 2010 study period; however, variability in the growth rates was high. For future monitoring efforts, sample sizes sufficient for statistical analysis across multiple intervals (which was not possible in this study or 2009 and 2010 comparison) will need to be collected to ensure that the initial area does not confound the detection and interpretation of pattern.

Lateral growth measurements have been used for much of the monitoring history of the FGB and results have shown overall growth of monitored margins, with high variability among individual colonies (Gittings et al. 1992; Dokken et al. 2001, 2003; Precht et al.

2006; Zimmer et al. 2010). Lateral growth measurements do not take into account the fact that individual corals may grow at different rates along different margins. For example, corals can die or retreat much faster than they can grow or advance, since disease and other factors causing mortality are capable of destroying tissue at a rapid rate, while growth occurs at a comparatively slow and more constant rate. While some marginal tissue may be advancing, other tissue on the same colony may be retreating, affecting the overall picture of lateral change in a given colony and by extension on a given bank and year. Also, lateral growth measurements do not take into account the accretionary growth of *Diploria strigosa*.

Other factors have affected the quality of lateral growth data from the long-term monitoring study for many years. Past researchers have encountered problems with locating lateral growth photostations, photographing the stations in a consistent way (e.g., at the same angle every time), and assessing photos that have not been taken in the proper orientation. Locating the photostations in the field (60 per bank) has proven to be time consuming due to missing pins and tags. The stations appear to have a short useful life because the colonies can overgrow the small area within the station in a short period of time. With 60 stations on each bank, it has also been a laborious task to keep them maintained, as they have to be re-established or repaired frequently, and there is not enough time on the monitoring cruises to repair or find new stations since other tasks take a priority. As of the 2010 research season, few comparable stations remained at either bank.

In 2010, many of the stations established years ago were completely overgrown by coral. This has resulted in the loss of many stations. Confusion by the frequent loss of marker pins and large changes in stations has resulted in photographs being taken in different orientations, making analysis difficult or impossible. Analysis of the photos has been difficult because it is hard to obtain true repetitive photographs since the framer is placed directly on the colonies. Because of the direct contact, the effects of increased rugosity and the changing orientation of margins caused by bioerosion, and accretionary growth also hinders repetitive photography. It is also difficult to replace lost corner bolts at precise locations. Lastly, the study site maps, largely based on previous researcher's maps, are continuously updated but are still not fully reliable. Due to these problems, it is recognized that not enough time is allotted for this effort. Improvements in methodology, mapping, establishing new stations, and extending cruise days to allow time for these tasks are necessary.

CHAPTER 7.0: PERIMETER VIDEOGRAPHY

7.1. PERIMETER VIDEOGRAPHY METHODOLOGICAL RATIONALE

Portions of the perimeter lines were videotaped each year at the EFGB and WFGB to document change at known locations along the perimeter of the study sites. General aspects of coral condition were documented and compared year to year.

7.2. PERIMETER VIDEOGRAPHY FIELD AND LABORATORY METHODS

Divers videotaped two 100 m segments of the perimeter lines at the EFGB (north and east margins) and WFGB (south and west margins) in 2009 and 2010. At the EFGB, divers began at the northwest corner of the 100 m x 100 m study site and videotaped the north line to the northeast corner, then swam the east line to the southeast corner. At the WFGB, divers captured footage of the south and west lines, beginning at the southeast corner and ending at the northwest corner. The videographer maintained an approximate 2.0 m (6.5 ft) distance above the bottom. The camera was aimed downward at a 45° angle to capture the substratum. In both years, a 360° panoramic view of the reef was videotaped at the three corners documented during the perimeter video. In both years, a Sony® Handicam® DCR-TRV950 video camera in a Light and Motion® Bluefin® housing with Light and Motion® Sunray® video lights. A red filter was used for color correction.

The video footage was reviewed to record the general condition of corals along the perimeter of the study sites. Individual coral colonies displaying possible disease, bleaching, paling, and tissue loss due to fish biting were identified and recorded. Analysis categories were as follows: disease, bleaching, paling, concentrated fish biting, and isolated fish biting. Concentrated fish biting (CFB) represents the concentrated biting that removes the coral polyps completely from an affected area and may be due to activity of the parrotfish *Sparisoma viride* (Bruckner and Bruckner 1998; Bruckner et al. 2000). Isolated fish biting describes less dense and smaller-scale fish biting, typically representative of damselfish territories. Affected coral colonies were compared in 2009 and 2010. Changes in coral colony condition were recorded. The perimeter surveys are intended to provide a general overview of ecosystem health. The analyses were qualitative; therefore, no statistical analyses were conducted on these data.

7.3. PERIMETER VIDEOGRAPHY RESULTS

The perimeter video was reviewed for a qualitative analysis of the general condition of corals along the perimeter of the study sites. In previous study years, fish population levels along the perimeter lines were also observed; however, due to the difficulty in identifying fish species in the videos, fish population information was collected in a more robust way, as described in a separate section of this report. The review of the 2009 and 2010 perimeter videos suggests that, in general, the coral community along the perimeter lines at the EFGB and WFGB study sites displayed low levels of stress and high cover. The most distressed corals were affected by paling and bleaching at WFGB in 2010. These results were comparable to random transect and repetitive quadrat data, although no statistical comparisons were made. Furthermore, no evidence of disease was observed at either bank.

7.3.1. EFGB Perimeter Lines

Two incidences of bleaching were observed at the EFGB in 2009, one being a *Montastraea faveolata* colony and the other a *Montastraea annularis* colony. In 2010, isolated fish biting (typical of damselfish) occurred on five colonies, followed by algal overgrowth (one colony), paling (one colony), and bleaching (seven colonies). *Montastraea franksi* was the coral species most impacted by these stressors. A comparison of corals affected by fish biting, disease, algal growth, paling, and bleaching in 2009 and 2010 at the EFGB is shown in Table 7.3.1.

Table 7.3.1.

Comparison of Observations of the Condition of Individual Coral Colonies at EFGB in 2009 and 2010

B= Bleaching, P= Paling, A= Overgrown by algae, D= Disease, IFB= Isolated fish biting, CFB= Concentrated fish biting

Number of Colonies	Coral Species	EFGB 2009	EFGB 2010
1	*Montastraea annularis*	B	
1	*Montastraea faveolata*	B	
2009 Total Affected Colonies = 2			
1	*Diploria strigosa*		B
1	*Diploria strigosa*		P
1	*Diploria strigosa*		A
1	*Montastraea annularis*		IFB
1	*Montastraea cavernosa*		B
1	*Montastraea cavernosa*		IFB
4	*Montastraea franksi*		B
2	*Montastraea franksi*		IFB
1	*Porites asteroides*		IFB
1	*Stephanocoenia intersepta*		B
2010 Total Affected Colonies = 14			

7.3.2. EFGB 360° Panoramic Views

At the northwest corner, corals appeared to be in good condition in both 2009 and 2010. In 2009, there were two Montastraea spp. Colonies that where paling and tissue loss occurred due to concentrated fish biting from numerous fish present. In 2010, it appeared these two colonies had recovered and were no longer paling. At the northeast corner, the corals appeared to be in good condition, with little evidence of bleaching stress or fish biting. Large fish populations were noted, including ocean trigger fish in 2009.

The southeast corner appeared to be in good health. There was little evidence of paling and bleaching in 2009, and one coral head displaying fish biting. The fish populations were similar between years and included Creole wrasse, Creolefish, and damselfish.

7.3.3. WFGB Perimeter Lines

In 2009, concentrated fish biting occurred on three colonies, isolated fish biting on one, and paling on three. *Montastraea faveolata* was the coral most impacted by these stressors. In 2010 at the WFGB, coral stress included bleaching (98 colonies), paling (27 colonies), concentrated fish biting (seven colonies), algal over growth (one colony), and disease (one colony). *Montastraea cavernosa* and *Millepora alcicornis* were the most impacted coral species (Table 7.3.2).

Table 7.3.2.

Comparison of Observations of the Condition of Individual Coral Colonies at WFGB from 2009 and 2010

B= Bleaching, P= Paling, A= Overgrown with algae, D= Disease, IFB= Isolated fish biting, CFB= Concentrated fish biting

Number of Colonies	**Coral Species**	**WFGB 2009**	**WFGB 2010**
1	*Millepora alcicornis*	P	
1	*Montastraea annularis*	IFB	
1	*Montastraea faveolata*	P	
3	*Montastraea faveolata*	CFB	
1	*Stephanocoenia intersepta*	P	
2009 Total Affected Colonies = 7			
1	*Colpophyllia natans*		B
1	*Colpophyllia natans*		P
4	*Diploria strigosa*		P
2	MASC		B
1	MASC		CFB
32	*Millepora alcicornis*		B
46	*Montastraea cavernosa*		B
1	*Montastraea cavernosa*		CFB, A
8	*Montastraea cavernosa*		P
1	*Montastraea faveolata*		B
1	*Montastraea faveolata*		CFB
1	*Montastraea faveolata*		D

Number of Colonies	Coral Species	WFGB 2009	WFGB 2010
1	*Montastraea faveolata*		P
2	*Montastraea franksi*		B
8	*Montastraea franksi*		P
1	*Porites astreoides*		B
13	Unidentified Coral		B
4	Unidentified Coral		CFB
5	Unidentified Coral		P
2010 Total Affected Colonies = 133			

7.3.4. WFGB 360° Panoramic Views

The southeast corner coral health was good in 2009 and 2010, with only one coral head affected by fish biting in 2009. In 2010, three colonies of *Montastraea cavernosa* and six colonies of *Millepora alcicornis* exhibited bleaching.

At the southwest corner, only one *Montastraea spp.* colony appeared to be paling in 2009. However, in 2010, the colony from the year before, six colonies of *Montastraea cavernosa* and 18 colonies of *Millepora alcicornis* exhibited paling or bleaching. Large fish populations were noted, including Ocean Triggerfish in 2009. Large barracudas were observed at the southwest corner in 2009.

The northwest corner coral health was good in 2009, with only one conspicuous paling *Millepora alcicornis* coral head. A large school of Brown Chromis was observed near the corner. In 2010, many more coral heads were bleached (nine colonies of *Montastraea cavernosa* and ten colonies of *Millepora alcicornis*, including the colonly from 2009).

7.4. PERIMETER VIDEOGRAPHY DISCUSSION

Videography of the perimeter lines and 360° panoramic views of the corner markers at the EFGB and WFGB provided a general overview of coral condition at the study sites from 2009 to 2010. Similar to the findings from the random transects, coral condition appeared to be relatively good at both banks in both years. There were no signs of coral disease. In previous years, the most noticeable impacts to coral colonies were concentrated and isolated fish biting; however, only a few incidences of fish biting were observed. In 2009 and especially in 2010, the most common impacts were coral paling and bleaching. For example, in Figure 7.4.1, a head of *Porites astreoides* is viewed as a healthy colony in the 2009 perimeter video, but shows as a bleached colony in the 2010 perimeter video.

It is important to note that a number of human errors may have influenced the qualitative data provided by the perimeter video and the 360° panoramic views. First, while the perimeter lines at both banks were generally in the same locations between years, the lines did shift (Figure 7.4.1). This is due to the affect of currents and surge on the flexible perimeter lines between the fixed corner markers, which are 100-m apart. In the future, there are plans to install mid-transect eye bolts during study site refurbishment activities to assist in improving repeatability so that transect lines can be attached to eye bolts to avoid shifting lines with the current.

Furthermore, there is an occasional need for reinstallation of missing corner markers, which usually is a slightly different position from previous locations. Shifting perimeter lines and corner marker positions result in a lack of overlapping video footage and fewer available coral comparisons. In addition, due to operator error, the 2 m height of the camera above the substratum and the 45º angle were not always maintained, changing the view of the bottom and affecting the analysis.

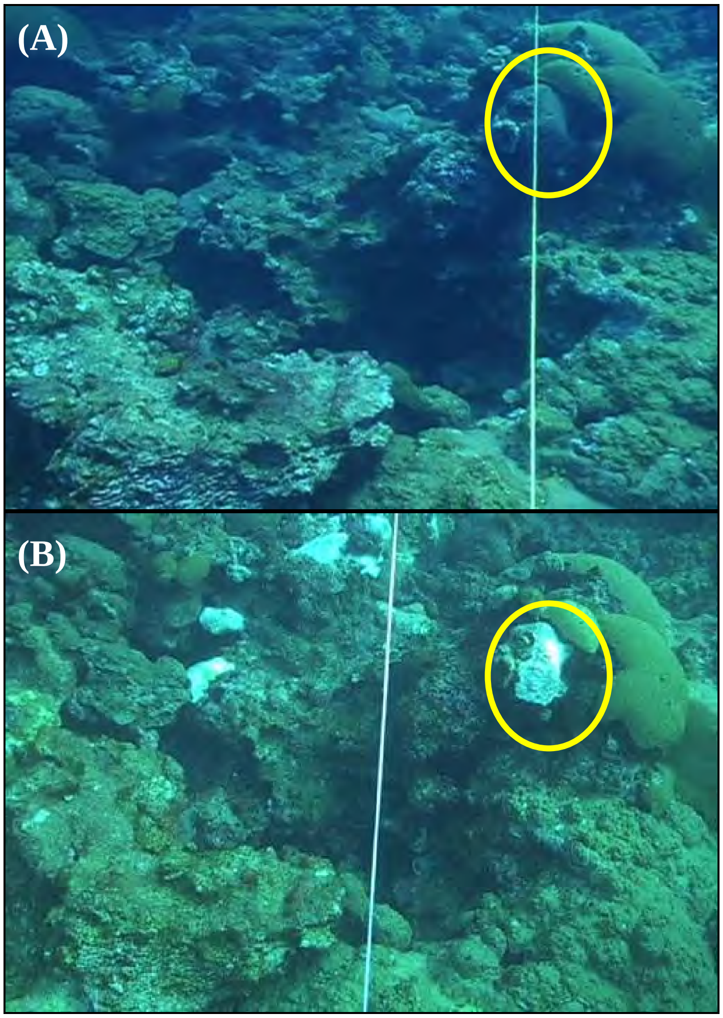


Figure 7.4.1. A head of *Porites astreoides* observed to be healthy in 2009 (A), but bleached in 2010 (B) at the WFGB.

CHAPTER 8.0: QUALITATIVE FIELD OBSERVATIONS

8.1. QUALITATIVE FIELD OBSERVATIONS METHODOLOGICAL RATIONALE

In addition to the annual data collection protocol, other biologically relevant information is documented on the reefs of the FGBNMS. During each annual monitoring cruise and other research cruises, observations of general coral reef health and notable biological and oceanographic events (e.g., spawning, animal behavior) were qualitatively assessed and documented.

8.2. QUALITATIVE FIELD OBSERVATIONS METHODS

As divers traversed the EFGB and WFGB study sites during the 2009 and 2010 annual monitoring cruises, they noted and photographically documented any biologically relevant observations and/or events.

8.3. QUALITATIVE FIELD OBSERVATION RESULTS

8.3.1. Wildlife Observations

8.3.1.1. Elasmobranch Sightings

During the 2009 EFGB annual monitoring cruise, three manta rays (*Manta birostris)* were sighted during diving operations. Each manta ray has a unique set of markings and color patterns on its ventral side. These can be used to identify individual rays. Of the three mantas seen at the EFGB in 2009, two were newly recorded mantas and one was a resighting of manta number M46 (Manta Photo Catalog discussed in Section 8.4) (Figure 8.3.1). One of the unidentified mantas was missing a portion of its posterior end and its tail. Manta rays were not sighted at the WFGB in 2009 during the monitoring period.

In 2010, two mantas were sighted at the EFGB, one measuring approximately 2.4 m (8 ft) in length and the second approximately 1.8 m (6 ft) in length. At the WFGB, a 12-foot manta was sighted in 2010. Also at the WFGB, two tiger sharks (*Galeocerdo cuvier*), one approximately 3 m (10 ft) in length and the other 2.4 m (8 ft) in length, were sighted in 2010.

Figure 8.3.1. Manta ray M46 observed at the EFGB in 2009 with spot and square ventral markings (J. Wiseman and S. Bernhardt).

8.3.1.2. Fish Sightings

At the EFGB deep stations, approximately five black grouper (*Mycteroperca bonaci*) and yellowmouth grouper (*Mycteroperca interstitialis*) were observed by divers in 2009. In 2010, a rare peppermint bass (*Serranus* sp.) was seen at the EFGB. In 2009 at the WFGB, a slipper lobster was observed, and a barracuda was seen at a cleaning station near a *Siderastrea* spp. coral head. At the WFGB in 2010, nesting sergeant major (*Abudefduf saxatilis*) damselfish were observed by divers. Two large black grouper were observed near the WFGB sand patch, and a large school of amberjack were also observed, although they are not frequently seen at the FGB. A large loggerhead sea turtle (*Caretta caretta*) was observed surfacing for a breath near the R/V *Manta*.

8.3.2. Coral Health Observations

8.3.2.1. Qualitative Coral Health Assessments

During the 2009 and 2010 annual monitoring cruises, scientific divers made qualitative observations of coral colonies exhibiting signs of disease or other coral health issues. During the 2009 monitoring cruise at the EFGB, divers experienced 100 foot visibility and water temperatures near 29°C (84°F). The *Madracis auretenra* (formerly named *Madracis mirabilis*) fields to the east of the study site were observed to be recovering from September 2008 Hurricane Ike impacts (Locke 2009).

In 2010, divers experienced a thermocline at approximately 12 m (40 ft), up to 21 m (70 ft) visibility, and a strong current due to a tropical depression that was moving into the Gulf of Mexico, causing conditions to change throughout the week. Visibility ranged from 15–21 m (50–70 ft). Divers observed false bleaching (white pigmentation that appears in certain corals), and an unidentified plague-like disease on multiple heads of *M. annularis*, *M. franksi*, and *M. faveolata*. The summer 2010 season was distinguished by increases of fluorescent orange algae growth at the EFGB and WFGB (Figure 8.3.2). The orange alga was very noticeable in the crevices of the reef, and samples were collected and sent to Dr. Suzanne Fredericq's Seaweeds Laboratory at the University of Louisiana at Lafayette for identification. The alga was identified as *Martensia pavonia*, a delicate net-forming alga that is a member of the Delesseriaceae family and exhibits a bright orange color in its deteriorating state. Algal blooms are classic indicators of high nutrient levels on coral reefs, and tend to expand in the warm season and during the rainy season when more nutrients are flushed offshore from land.

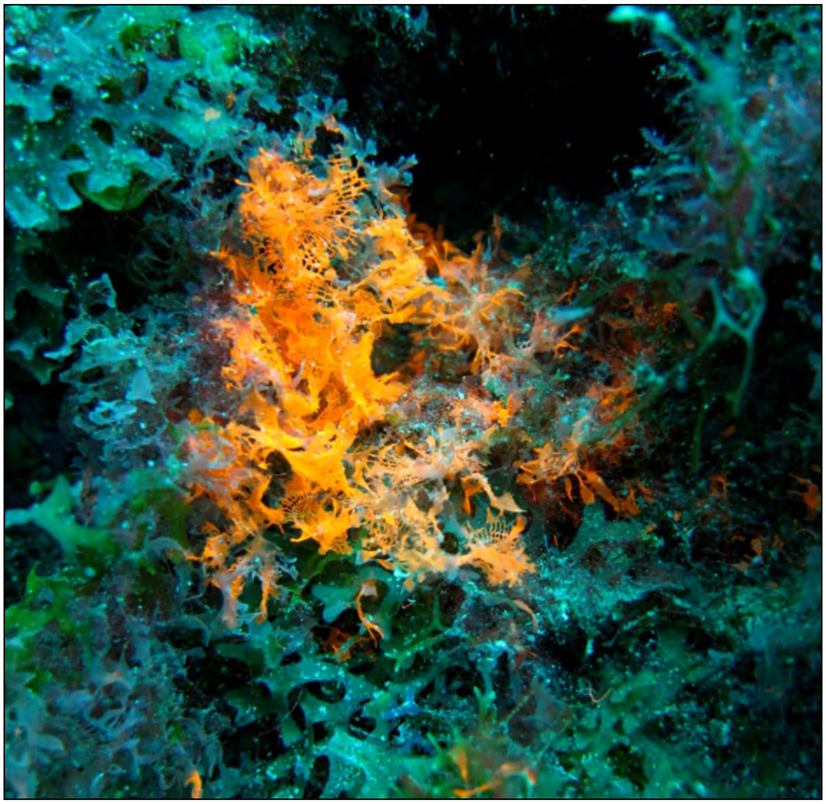


Figure 8.3.2. Fluorescent orange algae, *Martensia pavonia*, observed at the EFGB in 2010 (NOAA/FGBNMS).

There were no unusual observations at the WFGB in 2009, but in 2010, divers observed bleached corals at the WFGB, most likely due to warm seawater temperatures. The most common bleached corals included *Montastraea cavernosa*, *Millepora alcicornis*, and *Siderastrea siderea*.

8.3.2.2. Acropora palmata

During the June 2005 monitoring cruise, a colony of *Acropora palmata* (elkhorn coral) was discovered outside the EFGB study site, in close proximity to the southeast corner marker. *Acropora palmata* is a reef-building coral that has not been previously encountered at the FGB. The colony was located at a depth of 23.5 m (77.1 ft) and measured approximately 0.5 m (1.6 ft) in width and 1.0 m (3.3 ft) in height, with a maximum branch length of 30 cm (11.8 in) (Zimmer et al. 2006). As of October 2009, this *Acropora palmata* colony exhibited branch loss, which was likely due to the passage of Hurricane Ike in September 2008. In addition, the colony also displayed tissue loss on its southern side due to an unidentified cause and a white band of exposed coral skeleton on one of the branches. Algal farming (non-destructive cropping of algae, which promotes exponential growth for grazing) by a Threespot Damselfish (*Stegastes planifrons*) was also evident on the colony and may have contributed to the coral tissue loss. Despite these changes, in 2010 the colony displayed a normal yellow-brown color and appeared to be recovering and in good health (Figure 8.3.3).

In July 2003, an *A. palmata* colony was found at a depth of 21.6 m (70.9 ft) on the WFGB. This colony included an encrusting basal plate and one small branch. As of May 2005, the colony measured 0.6 m (2 ft) wide by 0.5 m (1.6 ft) high with a maximum branch length of 8.8 cm (3.5 in). In both 2009 and 2010, the colony appeared unhealthy, and suffering from disease. Algae covered the coral in places where it had already died (Figure 8.3.4).

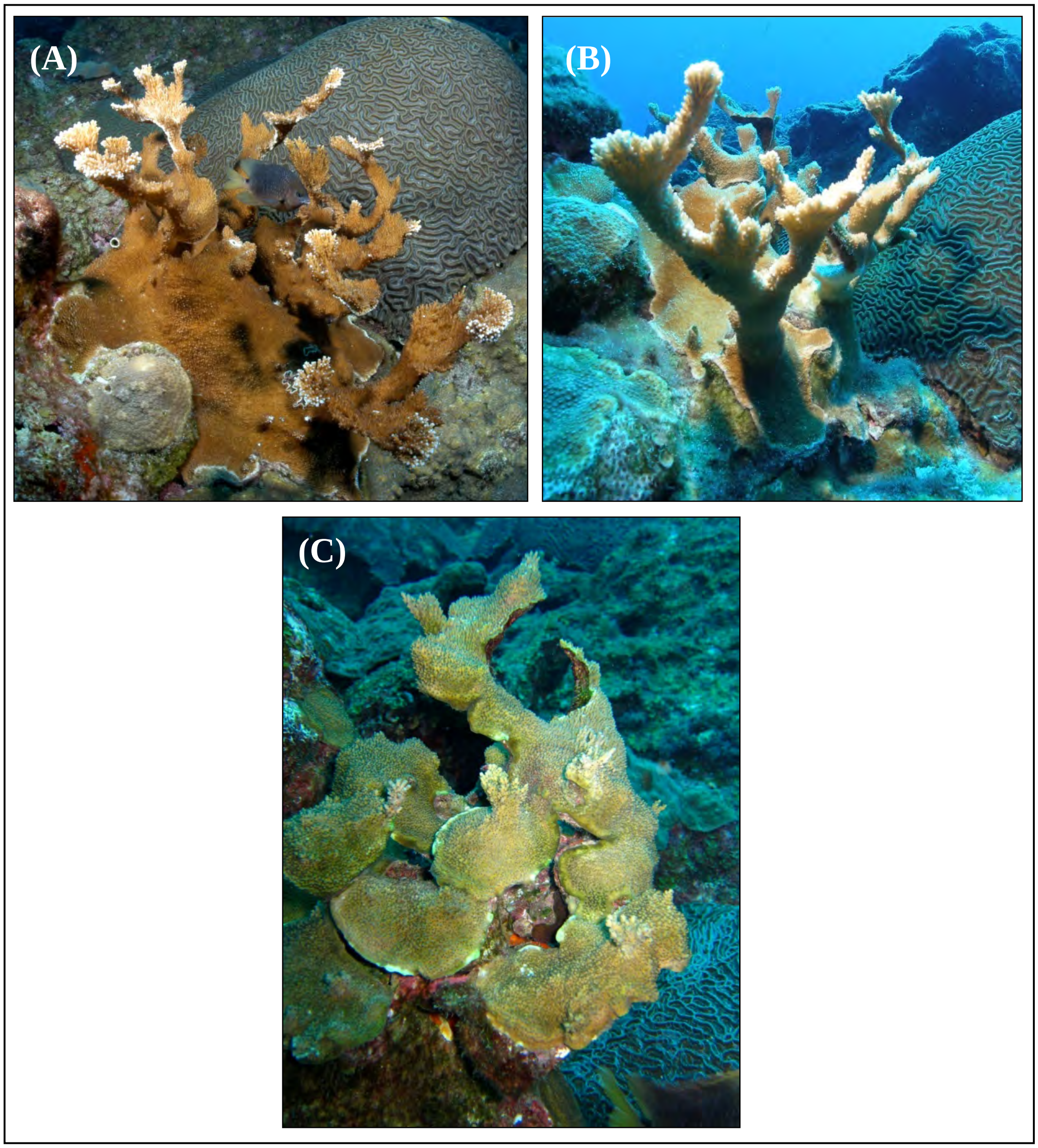


Figure 8.3.3. The *Acropora palmata* colony at the EFGB in (A) 2005 (B) 2006 and (C) 2010.

Note the resident damselfish in photo (A) (NOAA/FGBNMS).

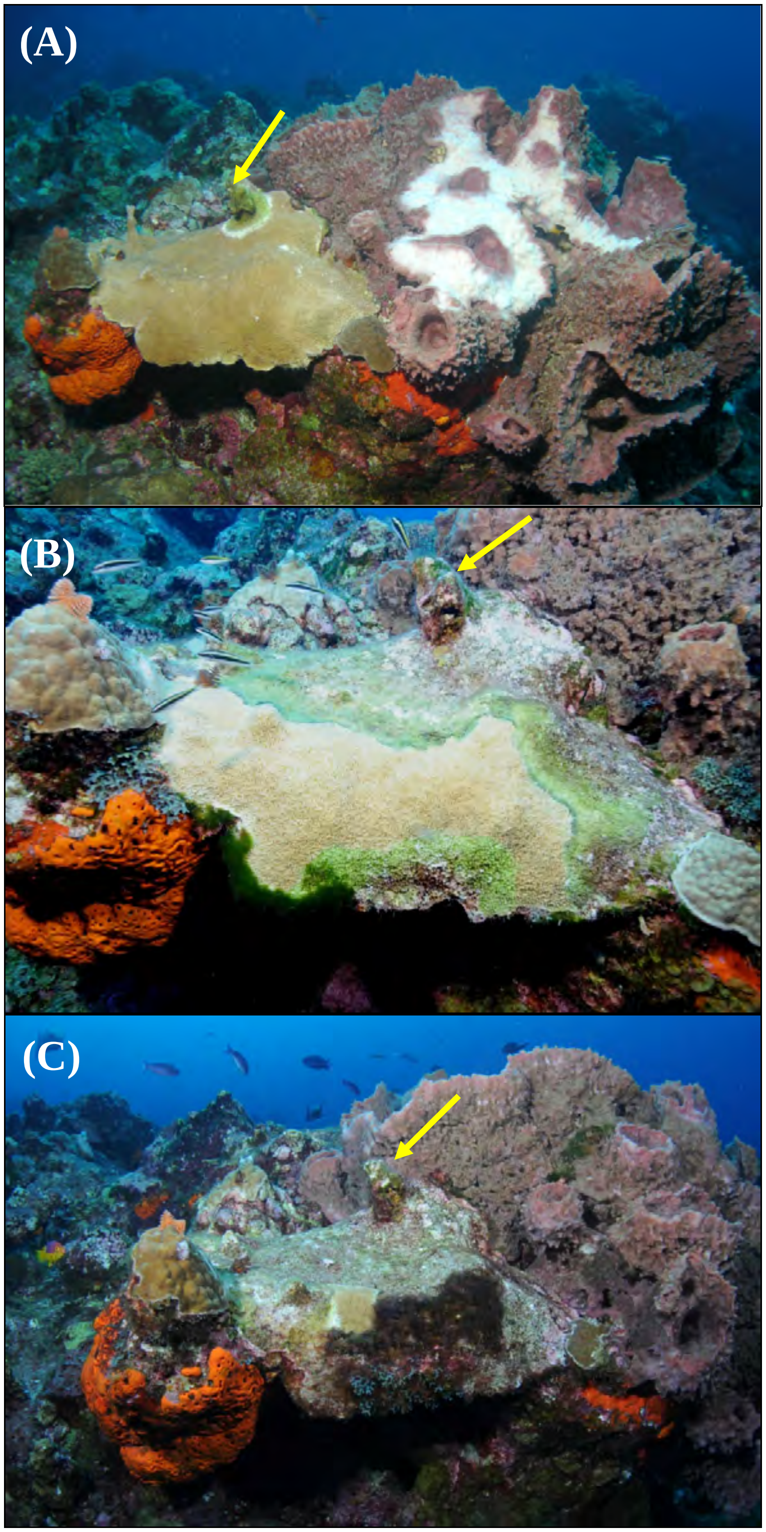


Figure 8.3.4. The only *Acropora palmata* colony at the WFGB is shown to be dying from disease in (A) 2008 (B) 2009 and (C) 2010.

Algae are taking over in places where the coral has already died (NOAA/FGBNMS).

8.3.3. Exotic and Invasive Species

In 2002, invasive orange cup coral (*Tubastraea coccinea*) was first documented at the EFGB. Orange cup coral is native to the Indo-Pacific and may have entered the South Atlantic and Caribbean by attaching to a ship's hull, having its larvae discharged in ballast water, or being transported on reused structures such as drilling rigs or production platforms. This species is now common on oil and gas platforms in the Gulf of Mexico, and it is suspected that platforms played a role in the spread of this species. In 2009 and 2010, sporadic colonies of cup coral were observed on the reefs near the EFGB and WFGB study sites (Figure 8.3.5).

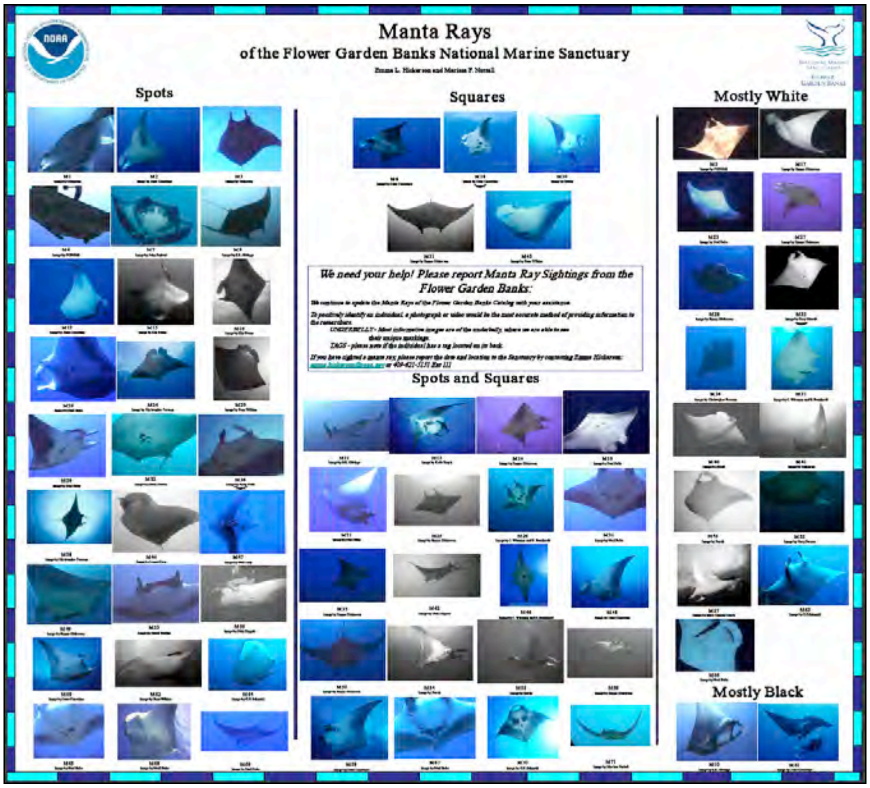
Figure 8.3.5. Orange cup coral (*Tubastraea coccinea)*, an invasive species from the Pacific that is beginning to establish itself at the FGBNMS (NOAA/FGBNMS).

8.4. QUALITATIVE FIELD OBSERVATIONS DISCUSSION

8.4.1. Wildlife Observations

8.4.1.1. Elasmobranch Sightings

Sanctuary staff and volunteers have been collecting photos and videos of mantas sighted in the sanctuary over many years. These photos are the basis of a FGBNMS Manta Ray Photo Catalog, identifying each of the known individuals and the additional of new individuals. The catalog can be viewed online and downloadable as a poster (Figure 8.4.1). The manta rays in the catalog have been divided into categories to aid in identifying individuals. Each manta ray is placed in a category according to its unique underbelly markings (i.e., spots, squares, spots and squares, mostly black, mostly white, and tagged). The catalog is an ongoing project, so new mantas and additional sightings of current mantas are added at every opportunity. Of the six mantas observed during 2009 and 2010, one could be positively identified as having been seen in the past.


Manta Rays
of the Flower Garden Banks National Marine Sanctuary

Spots

Squares

Mostly White

We need your help! Please report Manta Ray Sightings from the Flower Garden Banks:

Spots and Squares

Mostly Black

Figure 8.4.1. FGBNMS Manta Ray sighting catalog. The manta rays in the catalog have been divided into categories to aid in identifying individuals, each by its unique ventral markings (NOAA/FGBNMS).

The two tiger sharks observed in November 2010 at the WFGB are among approximately 20 species of sharks and rays have been documented at the Flower Garden and Stetson

Banks; some occurr seasonally, others year-round. During the late fall and winter months, frequent users of the sanctuary include tiger sharks, schooling scalloped hammerheads, and spotted eagle rays.

8.4.2. Coral Health Observations

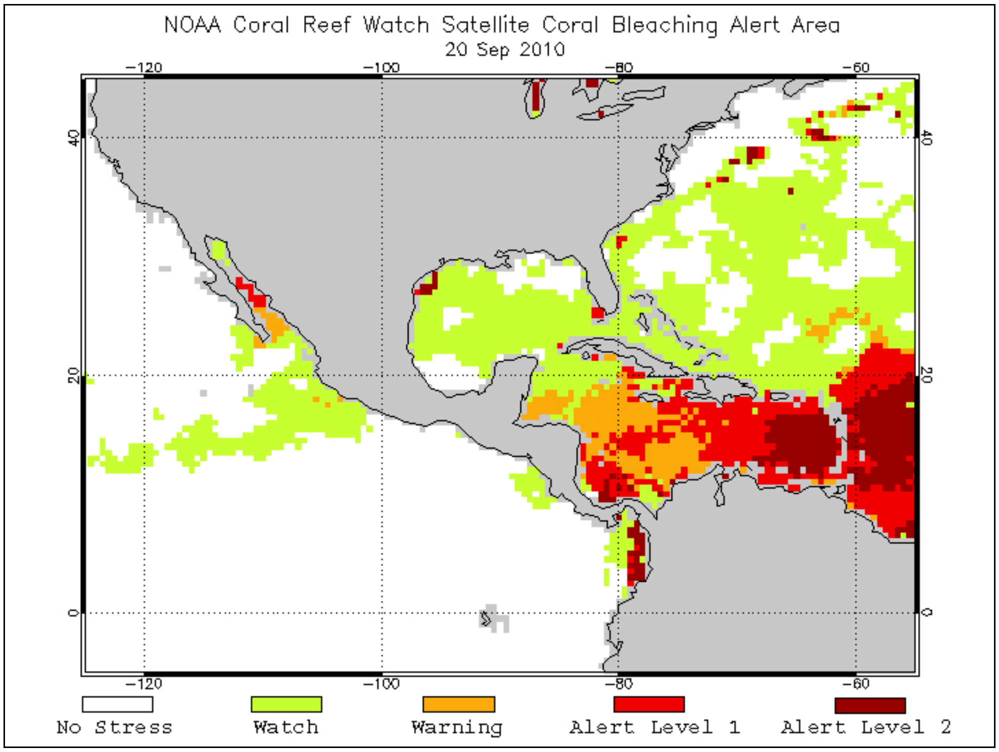
8.4.2.1. Qualitative Coral Health Assessments

In November of 2010, divers observed a higher than normal number of bleached coral colonies at the WFGB. The most common were *Montastraea cavernosa* and *Millepora alcicornis*. This was most likely a result of warm sea surface water temperatures in late summer of 2010, which exceeded the 30°C coral bleaching threshold for the Flower Gardens (Hagman and Gittings, 1992) during that season. Because these observations were taken after most of the data was collected during the August and October 2010 cruises, the bleaching of *Millepora alcicornis* is not reflected in the bleaching results from earlier sections of this report.

In September of 2010, NOAA's Coral Reef Watch Program's satellite data provided near-real time data on the reef environmental conditions in the Gulf of Mexico to quickly identify areas at risk for coral bleaching. The Coral Reef Watch uses remote sensing and *in situ* tools for near-real-time and long term monitoring, modeling and reporting of physical environmental conditions of coral reef ecosystems. Areas near and inside the FGBNMS boundaries were coded at bleaching alert “Watch” levels and “Alert Level 2” in the fall of 2010 (Figure 8.4.2).

Coral Reef Watch is part of the NOAA Coral Reef Conservation Program (CRCP) and the National Environmental Satellite Data and Information Service (NESDIS). The satellite product suite is a key aspect to NOAA's monitoring system for coral reef ecosystems, the Coral Reef Ecosystem Integrated Observing System (CREIOS). Continuous monitoring of sea surface temperature at global scales provides researchers and managers with tools to understand and better manage the complex interactions leading to coral bleaching. When bleaching conditions occur, these tools can be used to trigger bleaching response plans and support appropriate management decisions.

It should be noted that monitoring at the EFGB was conducted in August 2010, before bleaching and before signs were observed. However, monitoring at the WFGB occurred in the late fall when bleaching was at its peak and significantly visible. Based on qualitative surveys, the EFGB and WFGB response to bleaching are similar, so this could be considered a temporal comparison, and signs of coral bleaching stress, or coral recovering from bleaching stress, may be observed at the EFGB as well.



Areas near and inside the FGBNMS boundaries were coded at bleaching alert "Watch" levels and "Alert Level 2" in the fall of 2010 (NOAA/CRCP).

Figure 8.4.2. Coral Reef Watch bleaching alert map for the Gulf of Mexico in September 2010.

In 2010, divers also observed the fluorescent orange algae, *Martensia pavonia*, at the EFGB and WFGB. Algal growth often indicates excessive levels of nutrients moving from the coastal zone into offshore habitats, stimulating production. Coral reef ecosystems are sensitive to high concentrations of nitrogen and phosphorus, which promote algal overgrowth. Besides algal cover, reefs with high levels of nutrients in the water may be more susceptible to coral diseases. Along developed coastlines excess nutrients come from human sources, such as human sewage, livestock manures, and agricultural runoff. Nutrients carried offshore act as fertilizers for marine plants growth. Algae can be considered an early warning of changes in water quality and potential impacts to coral health.

8.4.2.2. *Acropora palmata*

Historically, *Acropora palmata* (elkhorn coral) and *A. cervicornis* (staghorn coral) were two of the most important reef-building coral species in the Caribbean (Bruckner 2002; Precht and Aronson 2006). On May 9, 2006, *A. palmata* was officially placed on the Endangered and Threatened Species List (71 FR 26852) as a threatened species. Populations of these acroporid species in the Caribbean were decimated in the 1970s and 1980s by white band disease, with few apparent signs of recovery (Aronson and Precht 2001b). Researchers estimate that the population of *A. palmata* in the Caribbean is less than 5% of their historical abundance (before the 1970s decline; Bruckner 2002). Threats to *Acropora* spp. include disease, coral bleaching, predation, storm damage, and human activities.

The *Acropora palmata* colony discovered on the EFGB during the June 2005 annual monitoring cruise represents the deepest report of *A. palmata* from the Caribbean and western Atlantic regions, as well as the first record of *Acropora* spp. anywhere in the northern Gulf of Mexico (Zimmer et al. 2006). *A. palmata* is typically considered a shallow-water species, primarily occupying depths of less than 5 m (Lighty et al. 1982). The virtual absence of this species from the reefs of the FGB has been ascribed to cold winter water temperatures, the substantial depths of the reef caps at the EFGB and WFGB (18 m minimum for both banks), and the remoteness of the FGB from potential sources of *A. palmata* larvae (e.g., the Florida Keys and Mexican reefs of the southern Gulf of Mexico; Bright et al. 1984, Schmahl et al. 2008). The *A. palmata* colony branch loss is most likely due to the passage of Hurricane Ike in 2008, and tissue loss on the colony may be due to algal farming by damselfish. The FGBNMS researchers continue to monitor the status of the two *A. palmata* colonies, and follow-up studies are proposed to document and explain the turn-on and turn-off mechanisms for *Acropora* reef development on these isolated reef complexes (Schmahl et al. 2008).

8.4.3. Exotic and Invasive Species

Invasive species have recently become a concern for marine resource managers because of the inherent potential negative impacts that they can cause. *Tubastraea coccinea*, orange cup coral, was first documented within the FGBNMS in 2002 (Fenner and Banks 2004) and has further established itself on nearby oil and gas infrastructure, as well as in discrete locations within the sanctuary. *Tubastraea coccinea* began to colonize Geyer Bank, which is located 52 km (32 mi) east of the EFGB, and approximately 50 colonies of *T. coccinea* were removed by sanctuary divers in 2004. Since that time, *T. coccinea* has become well established at Geyer Bank, and has also been documented near both the EFGB and WFGB study sites.

T. coccinea is a zooxanthellate scleractinian coral that is an exotic, invasive species within the Caribbean and western Atlantic (Fenner 1999, 2001; Fenner and Banks 2004). Native to the tropical Indo-Pacific and the eastern Atlantic (Cairns 2000), *T. coccinea* was first reported in the Caribbean in 1943 (Fenner and Banks 2004). No fossil evidence of this species has been found within the Caribbean (Cairns 1999). *Tubastraea coccinea* is typically located on the undersides of rocks or massive corals, in caves, and on rock walls (Glynn et al. 2008). It appears to compete particularly well on artificial substrates, which may account for its widespread dispersal. It is a hermaphroditic brooding coral that releases planula larvae year round (Cairns 2000; Glynn et al. 2008) and has a mean growth rate of approximately 3 cm^2/year (Vermeij 2006). This species reaches reproductive maturity at a small size (from as small as 2–10 polyps; Glynn et al. 2008) and at an early age (reproductively viable at approximately 1.5 years; Vermeij 2006). *T. coccinea* has the ability to compete effectively by forming thin tissue outgrowths (“runners”) that extend over the substrate until suitable substrate is encountered, at which time a new polyp forms (Vermeij 2005). These competitive mechanisms may put native benthos at risk.

From its native Indo-Pacific range, *Tubastraea coccinea* has now been introduced to the waters off Asia, Africa, Australia, North America, Central America, and South America (IUCN 2007; Ferreira 2003; Fenner and Banks 2004; Glynn et al. 2008). This species was first observed in the Caribbean in 1943 by Vaughn and Wells, and has since spread throughout the Caribbean and Bahamas (Glynn et al. 2008), Gulf of Mexico (Fenner and Banks 2004), and Brazil (Figueira de Paula and Creed 2004). Possible mechanisms of introduction to these regions include boat/ship hulls, ballast water, transport of marine structures/machinery (e.g., oil platforms; Ferriera 2003; Fenner and Banks 2004). *T. coccinea* has colonized many of the oil and gas platforms in the northwestern Gulf of Mexico (Sammarco et al. 2006). Based on the proximity of the many *T. coccinea*-colonized platforms to the reefs of the FGB, along with this invasive species' effective dispersal capacity, the FGB is potentially at risk for further invasion by *T. coccinea* (Sammarco et al. 2006).

It is recommended that the FGBNMS continue to monitor for *Tubastraea coccinea*, *Thecacera pacifica* (a sea slug documented at Stetson Bank in 2006), and other exotic species. Exotic species have the potential to harm native species via competition for space or resources, or by harboring pathogens or parasites. If a *T. coccinea* invasion becomes at problem at the EFGB and/or WFGB, an opportunistic removal program should be initiated. In Brazil, the Universidade do Estado do Rio de Janeiro (UERJ) has instituted a removal/eradication program titled "Projecto Coral-Sol" to eliminate the potential threat of *T. coccinea* in that region.

Over the last five years, one of the world's most popular ornamental aquarium fish, the native Indo-Pacific lionfish (*Pterios volitans/miles*), has invaded much of the southeast Atlantic and Caribbean region, beginning with the escape of a few individuals from aquaria in Florida about a decade ago (Morris and Whitfield 2009) (Figure 8.4.3). The proliferation of this species has occurred quickly due to early sexual maturation, high fecundity, ability to invade many habitats, and effectiveness in competing for food (they are voracious predators that have no known predators in the region) (Mumby et al. 2011). Lionfish subject small-bodied and juvenile reef fish to greatly elevated predation, and coral reefs are at risk of phase shifts mediated by secondary effects of changes in fish trophic structure (e.g. increasing algal cover caused by the loss of herbivores). The long-term consequences on reef biodiversity and function are not yet clear, but are a matter of grave concern to resource managers.

Lionfish were first captured in the southern Gulf of Mexico off the northern Yucatan Peninsula in December 2009. In September 2010, two lionfish were sighted at Sonnier Bank by Texas A&M University Galveston researchers. These were the first confirmed sightings of lionfish at the natural banks in the northwestern Gulf of Mexico, about 60 miles east of East Flower Garden Bank. In July 2011, the first lionfish to invade sanctuary waters was observed by divers. The FGBNMS will continue to monitor the sanctuary for this invasive species. The FGBNMS staff is currently in the process of working with other staff at sanctuary sites to develop Lionfish Research and Management plans. While there is little scientific evidence to support using biocontrol as a natural means to slow the invasion of the lionfish, the EFGB and WFGB provides a unique opportunity to conduct an experiment to measure the effectiveness of natural predation, and the influence of fishing on this natural control mechanism. The managers of the FGBNMS are currently in the process of investigating the use of an experimental research area to assess these questions.

Figure 8.4.3. Invasive lionfish at the West Flower Garden Bank.
Lionfish are native to the Indo-Pacific region and invaded the Gulf of Mexico in 2009 (NOAA/FGBNMS).

CHAPTER 9.0: WATER QUALITY

9.1. WATER QUALITY METHODOLOGICAL RATIONALE

During the reporting period, Sea-Bird and HoboTemp dataloggers deployed at the EFGB and WFGB recorded variations of temperature and salinity. Temperature and salinity depth profiles were also collected opportunistically throughout the field season, using an YSI probe. Water samples collected quarterly from the sea surface to the reef cap at the EFGB and WFGB were analyzed for chlorophyll *a* and nutrients (ammonia, nitrate, and nitrite, soluble reactive phosphorous and total Kjeldahl nitrogen [TKN]).

Hereafter, "water quality" will refer to the physical (temperature) and biological (chlorophyll *a* [chl *a*]), and chemical (salinity and nutrients) characteristics of the seawater overlying the FGB. This report presents the results of the water quality monitoring at the EFGB and WFGB conducted from July 2009 to November 2010, although temperature and salinity profiles were collected from January 2009 to December 2010.

9.2. WATER QUALITY FIELD AND LABORATORY METHODS

9.2.1. Sea-Bird Conductivity and Temperature Recorder

The Sea-Bird Electronics, Inc. (SBE) 37-SMP MicroCAT with RS-232 serial interface is a high-accuracy conductivity and temperature recorder designed for long-term oceanographic deployment (www.seabird.com). The MicroCATs used at the FGBNMS included pressure and sound velocity sensors. The primary role of the MicroCAT in this study was to accurately record temperature and salinity. The specifications (and typical stability) of the MicroCAT indicate an initial accuracy of 0.003 mS/cm (conductivity) and 0.002°C (temperature). The resolution of the instrument is 0.0001 mS/cm and 0.0001°C (Figure 9.2.1).

One Sea-Bird datasonde was deployed at the EFGB (23 m or 75 ft water depth) near buoy number five and one at the WFGB (27 m or 88.5 ft water depth) near buoy number two. Sand flats were used as deployment locations to accommodate the secure attachment of the datasondes to galvanized train wheels (Figure 9.2.2). Water quality data were recorded every 30 min. These instruments are returned to Sea-Bird Electronics, Inc., in Bellevue, Washington for annual calibration and maintenance.

9.2.1.1. Specific Conductance

Datasondes used a cell with four nickel electrodes to measure solution-conductance. Two of the electrodes were current driven, and two were used to measure the drop in voltage. Differences were converted into a specific conductance value and reported in milli-Siemens (milliohms). Salinity was later derived from the conductivity and temperature readings according to accepted algorithms and reported as practical salinity units (PSU).

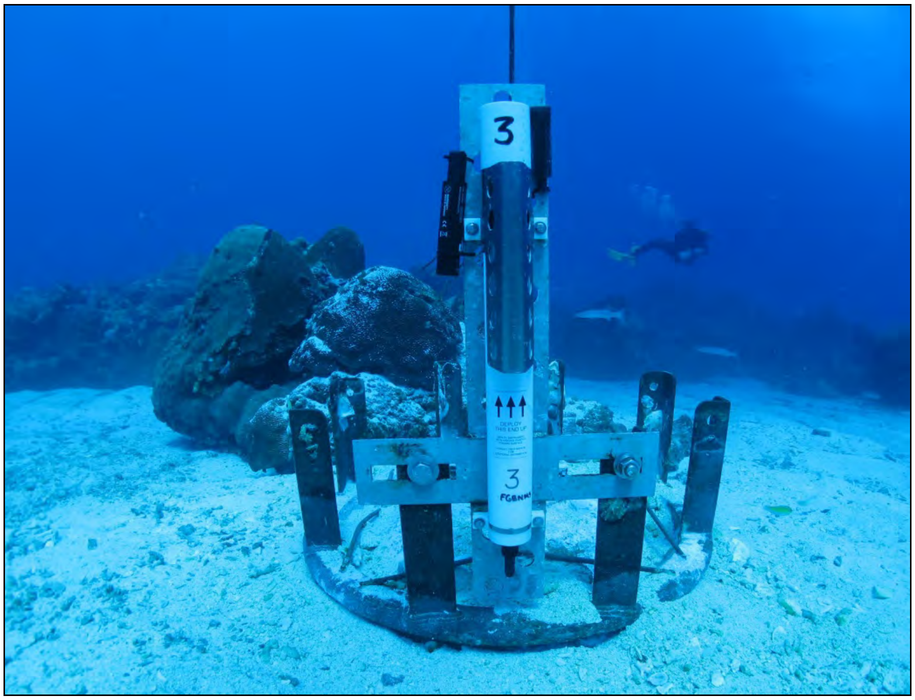


Figure 9.2.1. Sea-Bird 37-SMP MicroCAT water quality instrument at the EFGB (NOAA/FGBNMS).

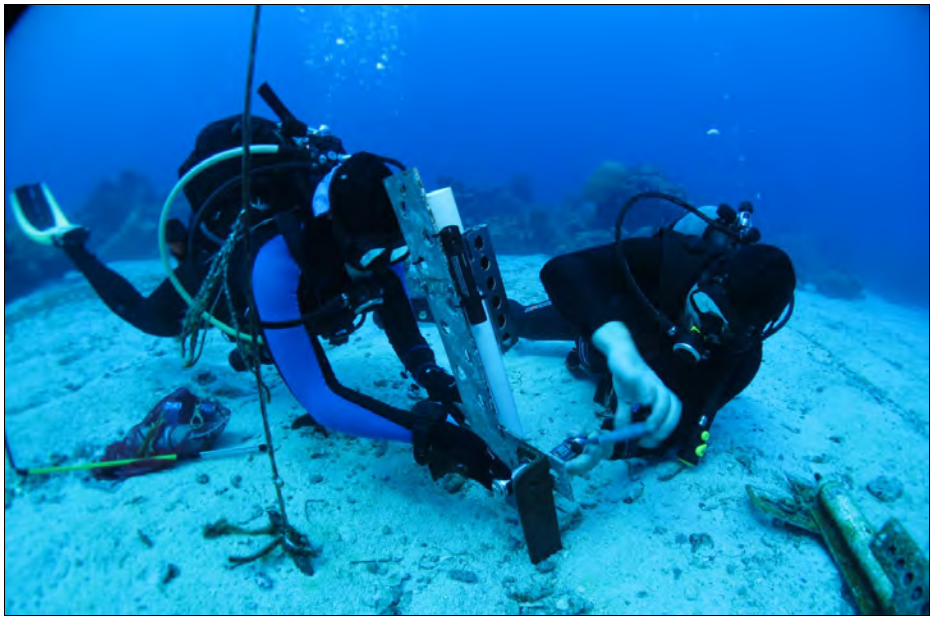


Figure 9.2.2. FGBNMS research divers mounting the Sea-Bird 37-SMP MicroCAT water quality instrument on a rack in the sand at the EFGB (NOAA/FGBNMS).

9.2.1.2. Temperature

The datasondes used a thermistor of sintered metallic oxide that changed predictably in resistance with variation in temperature. The algorithm for conversion of resistance to temperature was built into the datasonde software, and accurate temperature readings in degrees Celsius (°C), Kelvin (°K), or Fahrenheit (°F) were provided automatically. No user calibration or maintenance of the temperature sensor was necessary.

9.2.2. HoboTemp Thermographs

One HOBO Pro v2 Water Temperature Data Logger (HoboTemp) was attached to each of the Sea-Bird instruments as backup recorders of water temperature. HoboTemp recorders have an accuracy of ± 0.2°C and resolution is 0.02°C at 25°C. They are designed with a durable streamlined case for extended deployment in fresh or salt water, and equipped with an Optic USB interface for data offload in the field. The data loggers were deployed in a water depth of 23 m (75 ft) at the EFGB and in at 27 m (88.5 ft) at the WFGB and recorded every 30 min.

9.2.3. YSI Probe

During each cruise, opportunistic temperature profiles were measured by researchers using an YSI water quality sensor deployed by hand (Figure 9.2.3). Temperature and salinity were recorded at 20 m, 15 m, 10 m, 5 m, 4 m, 3 m, 2 m, 1 m, and the surface. These data complement the data collected by the stationary water quality instruments on the sea floor at each bank by providing additional information about the conditions throughout the water column.

Figure 9.2.3. FGBNMS researchers conducting seawater temperature profiles using a YSI probe through the moon pool of the R/V *Manta* (NOAA/FGBNMS).

9.2.4. Chlorophyll *a* and Nutrients

Surface (<1 m), midwater (10 m), and near bottom (20 m) water samples were acquired at six different times on the EFGB and WFGB between July 2009 and November 2010 (Table 9.2.1). During each sampling event, water was collected twice at each depth using a vertical 10 liter sampling bottle (Niskin®). Water samples were immediately transferred into pre-cleaned polyethylene and glass containers (tested monthly using nanopure water) provided by an independent, U.S. Environmental Protection Agency (USEPA) certified analytical laboratory (Anacon, Inc. in Houston, TX). Water samples were analyzed for chl *a*, ammonia, nitrate, nitrite, TKN, and soluble reactive phosphorous. Water samples for chl *a* analyses were collected in 1000 ml glass containers with no preservatives. Samples for reactive soluble phosphorous were placed in 250 ml bottles with no preservatives. Ammonia, nitrate, nitrite, and TKN samples were collected in 1000 ml bottles with sulphuric acid (H_2SO_4) as a preservative. One blind duplicate water sample was taken at one of the sampling depths on one of the banks for each sampling period. Within minutes of sampling, labeled sample containers were stored on ice at 4°C and a chain of custody was initiated. Once back onshore, the samples were sent to Anacon, Inc. for analysis using standard USEPA methods (Table 9.2.2) to assess concentrations of chl *a* and nutrients (ammonia, nitrate and nitrite, TKN, soluble reactive phosphorous).

Table 9.2.1.

Water Sampling Schedule, Depth, and Number of Samples Taken at the EFGB and WFGB in 2009 to 2010

EFGB			WFGB		
Sampling Date	**Depth**	**Samples**	**Sampling Date**	**Depth**	**Samples**
7/7/2009	1, 10, 20 m	6	7/8/2009	1, 10, 20 m	6
11/24/2009	1, 10, 20 m	6	11/24/2009	1, 10, 20 m	6
3/14/2010	1, 10, 20 m	6	3/14/2010	1, 10, 20 m	6
5/27/2010	1, 10, 20 m	6	5/27/2010	1, 10, 20 m	6
9/11/2010	1, 10, 20 m	6	9/13/2010	1, 10, 20 m	6
11/10/2010	1, 10, 20 m	6	11/9/2010	1, 10, 20 m	6

Table 9.2.2.

Standard USEPA Methods Used to Analyze Water Samples Taken at the FGB

mg/m³ = milligrams per cubic meter; mg/l = milligrams per liter

Parameter	Method	Detection Limit
Chlorophyll *a*	10200HPLC	1-mg/m³
Ammonia	E350.3	0.03–mg/l
Nitrate	E350.3	0.15–mg/l
Nitrite	E353.2	0.15–mg/l
Soluble reactive phosphorous	300.0	0.40–mg/l
Soluble reactive phosphorous	SM-4500-P	0.01–mg/l
Total Kjeldahl nitrogen (TKN)	E351.3	0.10–mg/l
Total Kjeldahl nitrogen (TKN)	E351.3	0.55–mg/l
Total Petroleum Hydrocarbons	THP-GRO - 1005	< 5

In May 2010, hydrocarbons were added to the suite of analysis parameters in response to the *Deepwater Horizon* oil spill. This measure was only added to this single sampling event as part of the oil spill response.

9.3. WATER QUALITY RESULTS

9.3.1. Sea-Bird Temperature and Salinity

9.3.1.1. Temperature

Seawater temperature was simultaneously measured on the reef caps of the EFGB (23 m or 75 ft water depth) and WFGB (27 m or 88.5 ft water depth) using a Sea-Bird 37-SMP MicroCAT datasonde from January 2009 to December 2010. The seawater temperature records were complete, with the exception of a gap from 01/01/2009 to 01/21/2009 at the EFGB due to a sensor malfunction that was reset on 01/22/2009. The temperature records include the winter minimum and summer maximum, and daily average temperatures were calculated. Appendix 5 contains the water quality data from 2009 and 2010 at the FGB.

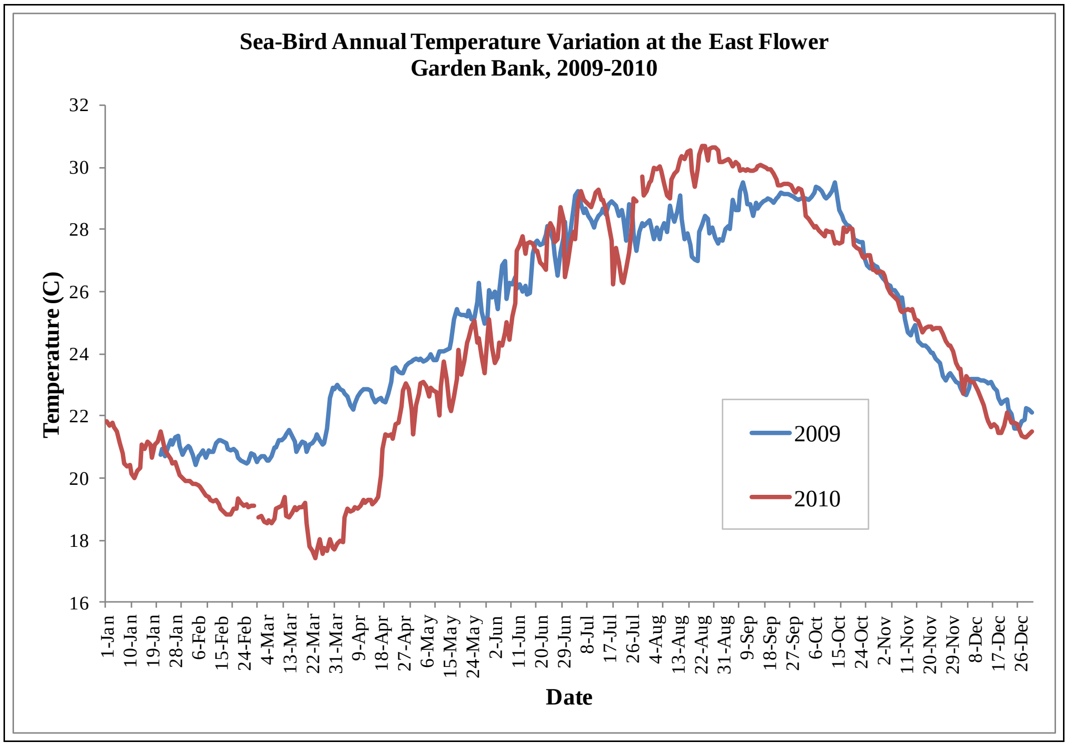
At the EFGB, temperature ranged from a minimum of 20.41°C to a maximum of 29.53°C in 2009. The annual mean temperature was 25.11°C. In 2010, the temperature ranged from 17.40°C to 30.69°C. The 2010 mean temperature was 24.46°C (Table 9.3.1).

Several thermal anomalies were recorded at the EFGB. There were episodes of low temperature in summer (June–September) of 2009 ranging from 25.45–27.54°C on the reef cap of the EFGB , as well as a sudden decrease in temperature (to 26.21°C) in late July 2010 at the EFGB. Late spring (March–May) temperatures in 2010 were also unusually low (17.40–21.40°C) at the EFGB. The temperature over the reef cap was high (29.26–30.69°C) during the summer and fall (July–November) of 2010. While the maximim temperature at the EFGB was less than 30°C in 2009, the maximum in 2010 exceeded 30°C. This is considered the coral bleaching threshold for the Flower Garden Banks (Hagman and Gittings 1992) (Figure 9.3.1).

Table 9.3.1.

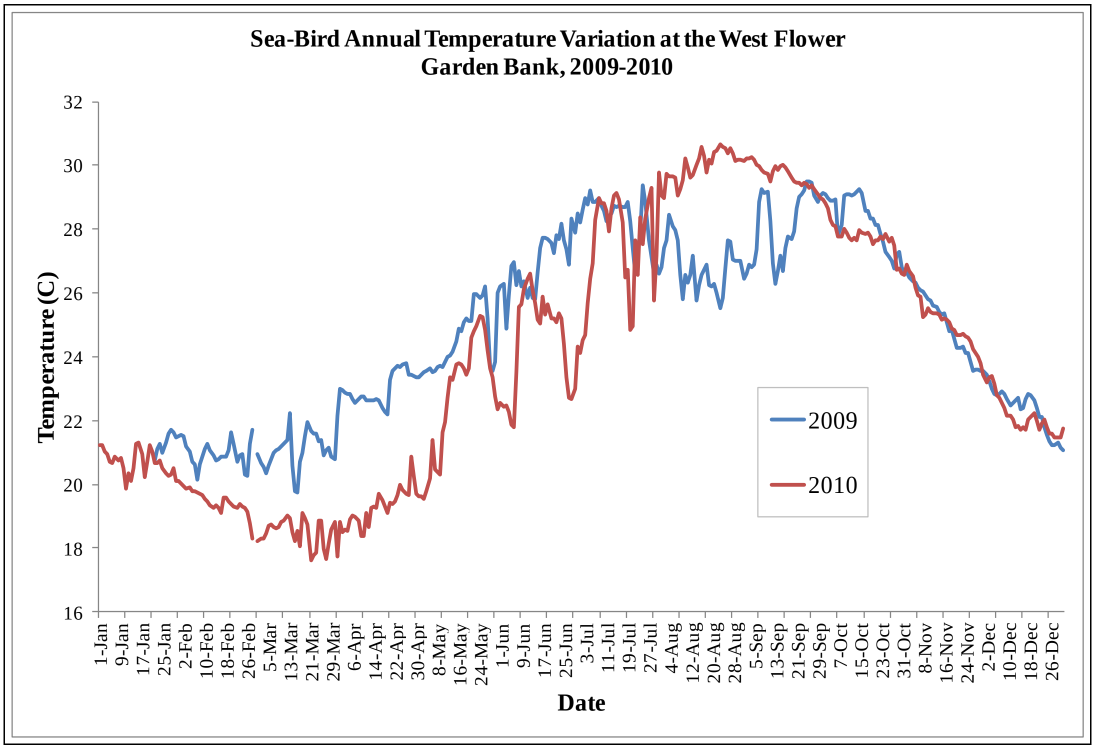
Summary of Sea-Bird Seawater Temperature Parameters from 2009 to 2010

Measurement	2009		2010	
	EFGB	WFGB	EFGB	WFGB
Annual Mean Temperature (°C)	25.11	24.95	24.46	23.96
Annual Minimum Temperature (°C)	20.41	19.76	17.40	17.63
Annual Maximum Temperature (°C)	29.53	29.50	30.69	30.64



Data obtained from Sea-Bird datasonde.

Figure 9.3.1. Daily average sea water temperature measured near the reef cap at the EFGB from 2009 to 2010.



Data obtained from Sea-Bird datasonde.

Figure 9.3.2. Daily average sea water temperature measured near the reef cap at the WFGB from 2009 to 2010.

At the WFGB, the annual daily mean temperature ranged from a minimum of 19.76°C to a maximum of 29.50°C in 2009. The annual mean temperature was 24.95°C. In 2010, temperature ranged from 17.63°C to 30.64°C. The annual mean temperature was 23.96°C (Table 9.3.1).

Several thermal anomalies were also recorded at the WFGB. There were episodes of low summer (July–September) temperature in 2009 (25.79–26.29°C), and a sudden decrease in temperature in June (21.85°C) and late July (24.83°C). Late spring (March–May) temperatures were also abnormally low (17.63–19.56°C) in 2010. The temperature over the reef cap was high (29.76–30.64°C) during the summer and fall (July–November) of 2010. Like the EFGB, the highest temperature in 2010 at the WFGB exceeded the 30°C coral bleaching threshold (Figure 9.3.2).

9.3.1.2. Salinity

Salinity records at the WFGB were complete between January 2009 and December 2010. At the EFGB, there were data gaps from 01/01/2009 to 01/21/2009 and from 06/30/2010 to 12/4/2010, both due to a sensor malfunctions Salinity ranged from approximately 31 to 38 PSU at the EFGB and WFGB from 2009 to 2010.

At the EFGB, the annual daily mean salinity ranged from 34.74 PSU to 36.99 PSU in 2009. The annual mean salinity was 36.53 PSU. In 2010, salinity ranged from 34.51 PSU to 37.75 PSU. The annual mean salinity was 36.56 PSU (Table 9.3.2). At the WFGB, the annual range was 30.97 to 36.68 PSU in 2009. The annual mean salinity was 35.18 PSU. In 2010, salinity ranged from 34.12 to 38.17 PSU. The annual mean was 36.37 PSU (Table 9.3.2).

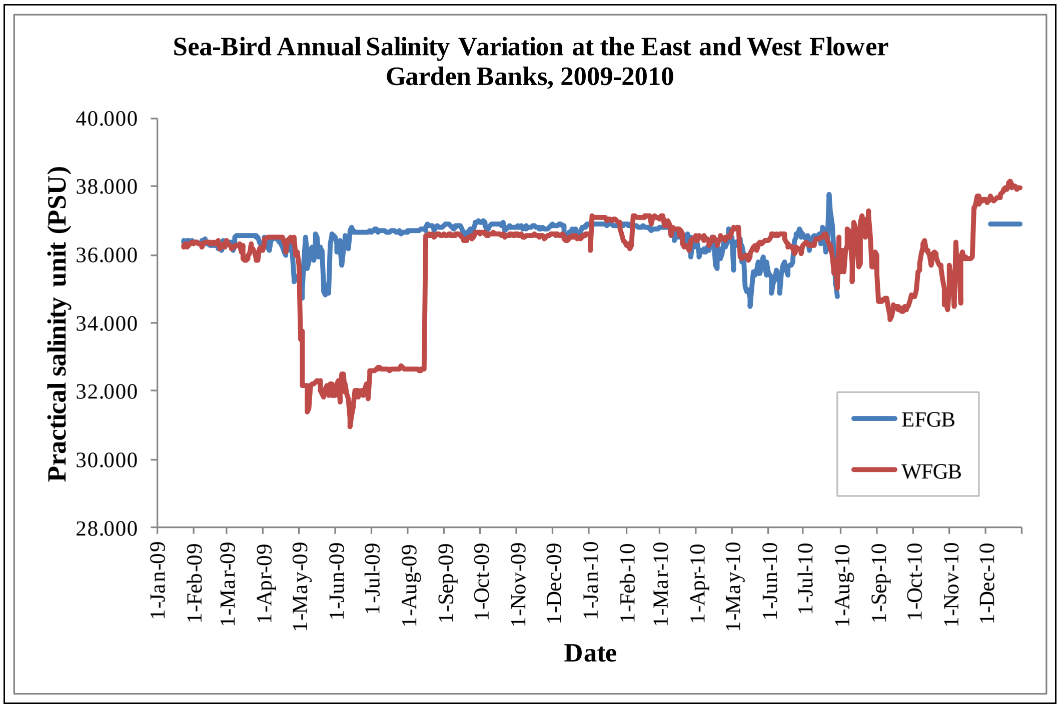
Table 9.3.2.

Summary of Sea-Bird Salinity Parameters from 2009 to 2010

Practical salinity unit (PSU)

Measurement	2009		2010	
	EFGB	WFGB	EFGB	WFGB
Annual Mean PSU	36.53	35.18	36.56	36.37
Annual Minimum PSU	34.74	30.97	34.51	34.12
Annual Maximum PSU	36.99	36.68	37.75	38.17

The WFGB experienced a period of low salinity from May to late August of 2009, even dropping below 31 PSU at one point. This was followed by salinities around 36 PSU in late August. The WFGB also experienced a smaller drop in salinity from September to November 2010. For the remainder of the 2009–2010 monitoring period, salinity was stable at approximately 36 PSU (Figure 9.3.3).



Data obtained from Sea-bird datasonde.

Figure 9.3.3. Salinity measured near the reef cap at the EFGB and WFGB from 2009 and 2010.

9.3.2. HoboTemp Thermograph Data

HoboTemp thermographs were attached to each of the Sea-Bird instruments at both banks from January 2009 through December 2010. The HoboTemp record provided similar data to that captured by the Sea-Bird datasondes: low average temperatures in the summer of 2009, an unusually cool spring in 2010, and high summer temperatures in 2010 (Figures 9.3.4. and 9.3.5).

At the EFGB, the HoboTemp temperature ranged from 20.35°C to 29.48°C in 2009. The annual mean was 25.07°C. In 2010, the annual mean ranged from 17.33°C to 30.08°C. The annual mean was 24.16°C (Table 9.3.3). At the WFGB, it ranged from 19.56°C to 29.67°C in 2009, with a mean of 24.91°C. In 2010, the range was 17.63°C to 30.77°C. The mean was 24.61°C (Table 9.3.3). These were not significantly different from the Sea-Bird temperature measurements.

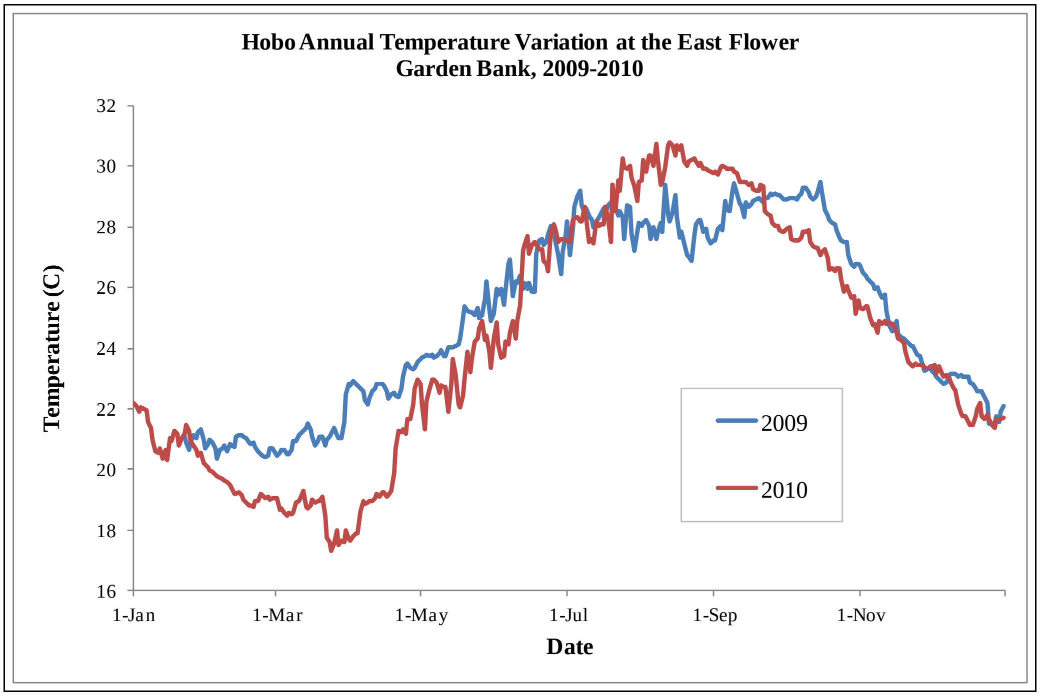


Figure 9.3.4. Daily average seawater temperature measured near the reef cap at the EFGB from 2009 to 2010. Data obtained from HoboTemp thermographs.

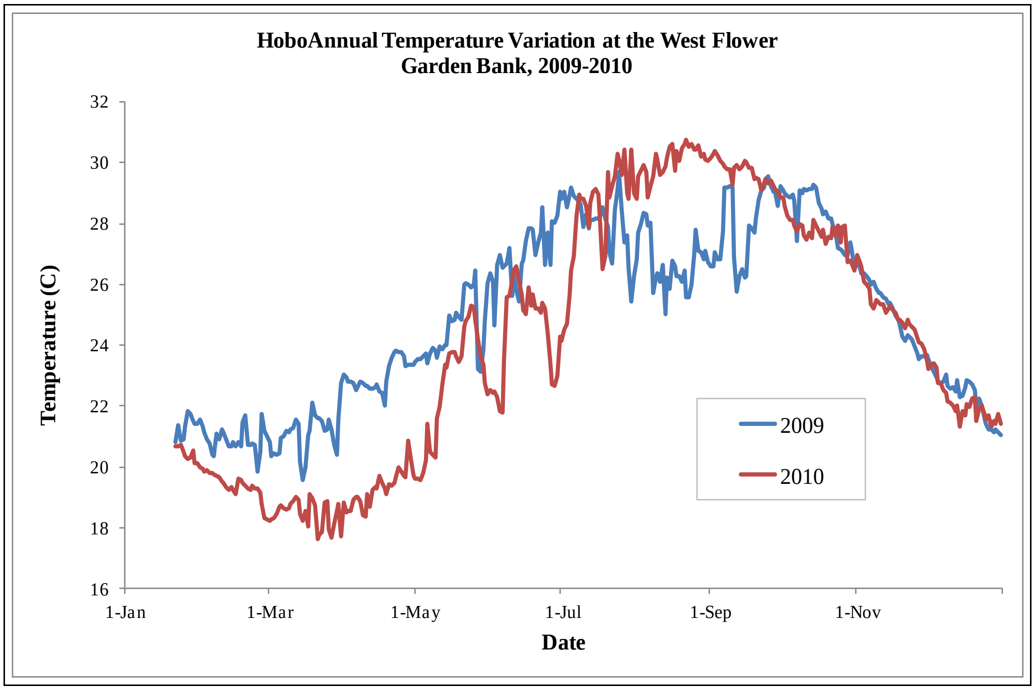


Figure 9.3.5. Daily average seawater temperature measured near the reef cap at the WFGB from 2009 to 2010. Data obtained from HoboTemp thermographs.

Table 9.3.3.

Summary of HoboTemp Seawater Temperature Parameters from 2009 to 2010

Measurement	**2009**		**2010**	
	EFGB	**WFGB**	**EFGB**	**WFGB**
Annual Mean Temperature (°C)	25.07	29.67	24.16	24.61
Annual Minimum Temperature (°C)	20.35	19.56	17.33	17.63
Annual Maximum Temperature (°C)	29.48	24.91	30.08	30.77

9.3.3. YSI Vertical Profiles

During each cruise, opportunistic seawater temperature profiles were measured by researchers using an YSI probe deployed by hand. Temperature was recorded at 20 m, 15 m, 10 m, 5 m, 4 m, 3 m, 2 m, 1 m increments, and at the water surface (Table 9.3.4). These data complement the data collected by the stationary water quality instruments on the sea floor at each bank by giving additional information, if needed, about the conditions at the surface and throughout the water column. YSI profiles corroborated the high water temperatures in August 2010. They also indicate the lack of a pronounced thermocline between the surface and 20 m during any times of the year.

Table 9.3.4.

Summary of Opportunistic YSI Seawater Temperature Vertical Profiles from 2009 to 2010 at the EFGB and WFGB

NA=Not available

				Temperature (°C)								
				Depth (m)								
Bank	**Buoy**	**Date**	**Time**	0.0	1.0	2.0	3.0	4.0	5.0	10.0	15.0	20.0
EFGB	7	1/21/2009	20:15	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
EFGB	7	1/22/2009	11:05	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
EFGB	1	3/14/2010	11:45	18.8	18.8	18.8	18.8	18.8	18.8	18.7	18.7	18.7
EFGB	1	5/27/2010	12:21	26.9	26.9	26.9	26.9	26.9	27	26.8	25.8	25.1
EFGB	1	6/5/2010	NA	28.1	28.0	28.0	28.0	27.9	27.8	27.5	27.4	27.6
EFGB	4	7/30/2010	17:55	30.8	30.7	30.7	30.6	30.4	30.4	30.1	29.7	29.4
EFGB	4	8/31/2010	23:03	30.2	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3
EFGB	2	8/31/2010	NA	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
EFGB	5	9/11/2010	7:09	29.6	29.5	29.6	29.6	29.7	29.7	29.9	29.8	29.8
EFGB	5	9/11/2010	18:35	30.7	30.5	30.2	30.0	30.0	30.0	30.0	29.9	NA
EFGB	5	9/12/2010	6:44	30.2	30.2	30.2	30.2	30.2	30.1	24.9	29.8	NA
EFGB	4	11/10/2010	15:16	25.2	25.2	25.2	25.2	25.2	25.2	25.3	25.3	NA
EFGB	4	12/4/2010	16:25	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.5	23.5
WFGB	2	1/22/2009	NA	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
WFGB	4	3/14/2010	13:53	18.7	18.7	18.7	18.7	18.6	18.6	18.6	18.5	18.4
WFGB	1	5/27/2010	14:45	27	27	26.9	26.9	26.9	26.9	26.7	26.6	25
WFGB	1	6/5/2010	NA	27.5	27.5	27.4	27.3	27.3	27.3	27.2	27.1	26.8
WFGB	1	7/30/2010	19:45	30.7	30.6	30.6	30.6	30.6	30.7	29.6	29.7	28.2
WFGB	1	7/31/2010	7:09	30.1	30.1	30.1	30.1	30.1	30.1	30	29.5	29.7
WFGB	2	8/30/2010	NA	30.5	30.5	30.5	30.4	30.4	30.3	30.2	30.2	30.2
WFGB	1	9/1/2010	9:54	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.3
WFGB	NA	9/13/2010	6:59	30.1	30.1	30.1	30.1	30.1	30.1	30.1	30	29.9
WFGB	NA	9/14/2010	11:59	30.1	30.1	30.0	30.0	30.0	30.0	29.9	29.8	29.6
WFGB	5	11/9/2010	9:55	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.3	25.3
WFGB	5	10/10/2010	9:03	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.4

9.3.4. Water Samples

9.3.4.1 Chlorophyll a and Nutrients

Surface (<1 m), midwater (10 m), and near bottom (20 m) water samples were acquired at 6 different times on both the EFGB and WFGB for the 2009 and 2010 monitoring period. Water samples were analyzed for chlorophyll *a* (chl *a*) and nutrients (ammonia, nitrate, nitrite, soluble reactive phosphorous, and total Kjeldahl nitrogen [TKN]).

Approximately 15% of the water samples collected contained concentrations of chl *a* that were above detectable limits (>1 mg/m³). Most were those collected in May 2010, specifically those from midwater and at the reef cap at the EFGB, and throughout the water column at the WFGB. The highest concentration detected was 2.14 mg/m³ of chl *a* (Table 9.3.5).

Table 9.3.5.

Chlorophyll *a* Concentrations in Water Samples Taken at the EFGB and WFGB from 2009 to 2010

ND=Not detected at reporting limit

Chlorophyll *a* (Detection limit: 1 mg/m³)	**2009**		**2010**			
	7/7/2009 – 7/8/2009	**11/24/09**	**03/14/10**	**05/27/10**	**9/11/2010 – 9/13/2010**	**11/09/2010 – 11/10/2010**
EFGB Surface A	ND	ND	ND	ND	ND	ND
EFGB Surface B	ND	ND	ND	ND	ND	ND
EFGB Midwater A	ND	2.14	ND	1.34	ND	ND
EFGB Midwater B	ND	ND	ND	1.07	ND	ND
EFGB Reef Cap A	ND	ND	ND	2.14	ND	ND
EFGB Reef Cap B	ND	ND	ND	1.87	ND	ND
WFGB Surface A	ND	ND	ND	1.34	ND	ND
WFGB Surface B	ND	ND	ND	1.07	ND	ND
WFGB Midwater A	ND	ND	ND	1.07	ND	ND
WFGB Midwater B	2.14	ND	ND	1.6	ND	ND
WFGB Reef Cap A	ND	ND	ND	1.07	ND	ND
WFGB Reef Cap B	ND	ND	ND	ND	ND	ND

Eighteen percent of water samples contained concentrations of ammonia above detectable limits. Ammonia was detected in all samples taken from 07/07 to 08/2009 at the EFGB and WFGB and ranged from 0.05 to 0.09 mg/l (Table 9.3.6). The modal value for ammonia levels was 0.03 mg/l. Samples containing the greatest amount of ammonia were obtained at the WFGB on 07/08/2009.

In approximately 87% of water samples, the nitrate concentrations were below detection limits (0.15 mg/l). The only samples that contained detectable levels were those collected at both banks in November 2009 and the WFGB in September 2010 (Table 9.3.6). Nitrite was not detected in any of the tested samples.

TKN was detectable in all water samples collected at the EFGB and WFGB in 2009, but only sporadically after that. Concentrations ranged from 0.84 to 13.9 mg/l (Table 9.3.6). Approximately 10% of the samples from 2010 contained TKN concentrations above detectable limits, ranging from 0.10 to 1.34 mg/l. Soluble reactive phosphorous was not detected in any of the tested samples.

Table 9.3.6.

Concentrations of Ammonia, Nitrate, and TKN in Water Samples Taken at the EFGB and WFGB from 2009 to 2010

Nitrite and soluble reactive phosphorous were not detected in any samples. ND=Not detected at reporting limit.

	2009		2010			
Ammonia (Detection limit: 0.03 mg/l)	**7/7/2009 – 7/8/2009**	**11/24/09**	**03/14/10**	**05/27/10**	**9/11/2010 – 9/13/2010**	**11/09/2010 – 11/10/2010**
EFGB Surface A	0.06	ND	ND	ND	ND	ND
EFGB Surface B	0.06	ND	ND	ND	ND	ND
EFGB Midwater A	0.08	ND	ND	ND	ND	ND
EFGB Midwater B	0.07	ND	ND	ND	ND	ND
EFGB Reef Cap A	0.07	ND	ND	ND	ND	ND
EFGB Reef Cap B	0.06	ND	ND	ND	ND	ND
WFGB Surface A	0.06	ND	ND	ND	ND	ND
WFGB Surface B	0.08	ND	ND	ND	ND	ND
WFGB Midwater A	0.05	ND	ND	ND	ND	ND
WFGB Midwater B	0.09	ND	ND	0.1	ND	ND
WFGB Reef Cap A	0.06	ND	ND	ND	ND	ND
WFGB Reef Cap B	0.06	ND	ND	ND	ND	ND
Nitrate (Detection limit: 0.15 mg/l)	**7/7/2009 – 7/8/2009**	**11/24/09**	**03/14/10**	**05/27/10**	**9/11/2010 – 9/13/2010**	**11/09/2010 – 11/10/2010**
EFGB Surface A	ND	0.17	ND	ND	ND	ND
EFGB Surface B	ND	ND	ND	ND	ND	ND
EFGB Midwater A	ND	0.18	ND	ND	ND	ND
EFGB Midwater B	ND	ND	ND	ND	ND	ND
EFGB Reef Cap A	ND	ND	ND	ND	ND	ND

	2009		2010			
Ammonia (Detection limit: 0.03 mg/l)	**7/7/2009 – 7/8/2009**	**11/24/09**	**03/14/10**	**05/27/10**	**9/11/2010 – 9/13/2010**	**11/09/2010 – 11/10/2010**
EFGB Reef Cap B	ND	0.18	ND	ND	ND	ND
WFGB Surface A	ND	0.2	ND	ND	1.34	ND
WFGB Surface B	ND	ND	ND	ND	ND	ND
WFGB Midwater A	ND	0.16	ND	ND	ND	ND
WFGB Midwater B	ND	0.27	ND	ND	0.88	ND
WFGB Reef Cap A	ND	ND	ND	ND	ND	ND
WFGB Reef Cap B	ND	ND	ND	ND	2.52	ND
TKN (Detection limit: 0.10 mg/l)	**7/7/2009 – 7/8/2009**	**11/24/09**	**03/14/10**	**05/27/10**	**9/11/2010 – 9/13/2010**	**11/09/2010 – 11/10/2010**
EFGB Surface A	0.98	4.70	ND	ND	ND	ND
EFGB Surface B	1.40	13.90	ND	1.12	ND	ND
EFGB Midwater A	1.96	10.60	ND	ND	ND	ND
EFGB Midwater B	1.26	2.40	ND	ND	ND	ND
EFGB Reef Cap A	1.96	1.60	0.7	ND	ND	ND
EFGB Reef Cap B	1.26	3.70	ND	ND	ND	ND
WFGB Surface A	1.40	5.80	ND	ND	1.34	1.31
WFGB Surface B	1.40	1.90	ND	ND	ND	ND
WFGB Midwater A	0.84	2.10	ND	ND	ND	ND
WFGB Midwater B	1.12	10.90	ND	0.1	0.88	ND
WFGB Reef Cap A	1.54	4.4	ND	ND	ND	ND
WFGB Reef Cap B	1.26	1.0	ND	ND	2.52	ND

9.3.5. Hydrocarbons

In response to the *Deepwater Horizon* oil spill, total petroleum hydrocarbons (TPH) were added to the suite of analysis parameters for the May 2010 water quality sampling at the EFGB and WFGB. This measure was only added to this one sampling event as part of the oil spill response. Water collected at the surface, midwater, and at the reef cap were analyzed for hydrocarbons. Total petroleum hydrocarbon concentrations were undetectable (>5 mg/L) in all water samples at both the EFGB and WFGB.

9.4. WATER QUALITY DISCUSSION

9.4.1. Water Quality Parameters

Water quality parameters investigated at the EFGB and WFGB from January 2009 through December 2010 were temperature, salinity, chl *a*, and nutrients (ammonia, nitrate, nitrite, soluble reactive phosphorous, and TKN). The accuracy of the temperature and salinity observations reported depended largely on the performance of the sensors during long-term oceanic deployments.

9.4.1.1. Sea-Bird versus Hobo Temperature Records

HoboTemp thermographs were attached to each of the Sea-Bird 37-SMP MicroCAT datasondes as backup records of seawater temperature, and data were acquired at the both banks from January 2009 through December 2010. Concurrent Sea-Bird and Hobo data could therefore be compared to evaluate accuracy. Overall, both methods provided reliable temperature records. Statistical comparisons were conducted to compare daily averages from 2009 to 2010 using a two-sample t-test. No significant differences (P-value >0.05) were found. However, one or both of the sensors at the EFGB apparently began to provide inaccurate readings during July of 2010 (see July–December data in Figure 9.4.1). The WFGB Sea-Bird and Hobo temperature data had only slight differences at the WFGB in late July of 2010 (Figure 9.4.2). Both the Sea-Bird and Hobo Temp thermographs will continue to be used at the FGB to enhance long-term monitoring of temperature on the reef cap, as well as provide reliable backup records if one sensor fails.

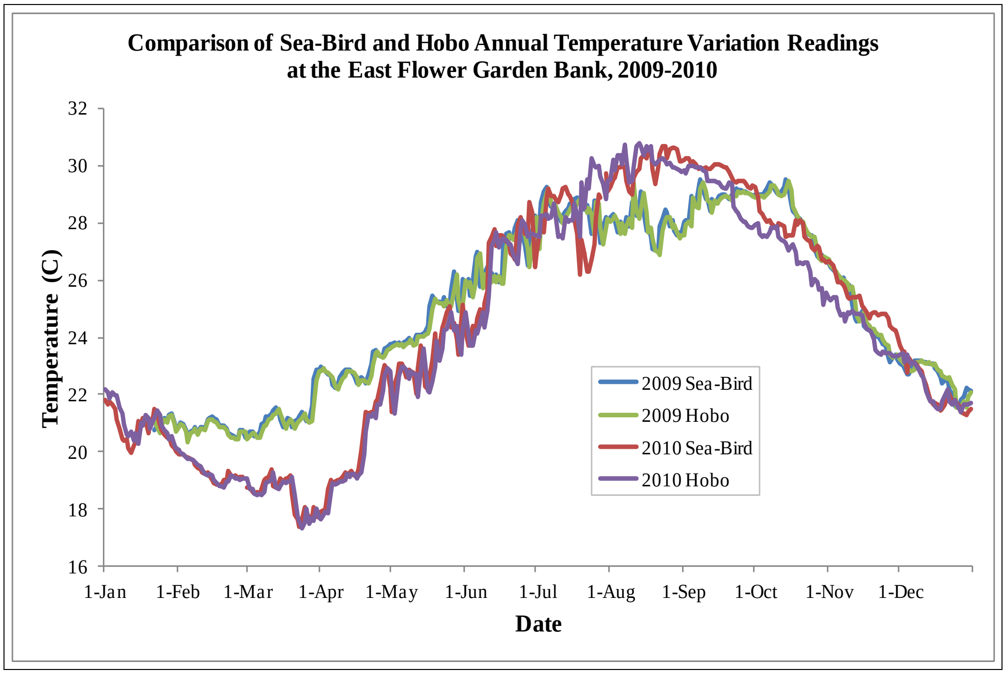


Figure 9.4.1. Comparison of Sea-Bird and Hobo daily average sea water temperature readings measured near the reef cap at the EFGB from 2009 to 2010.

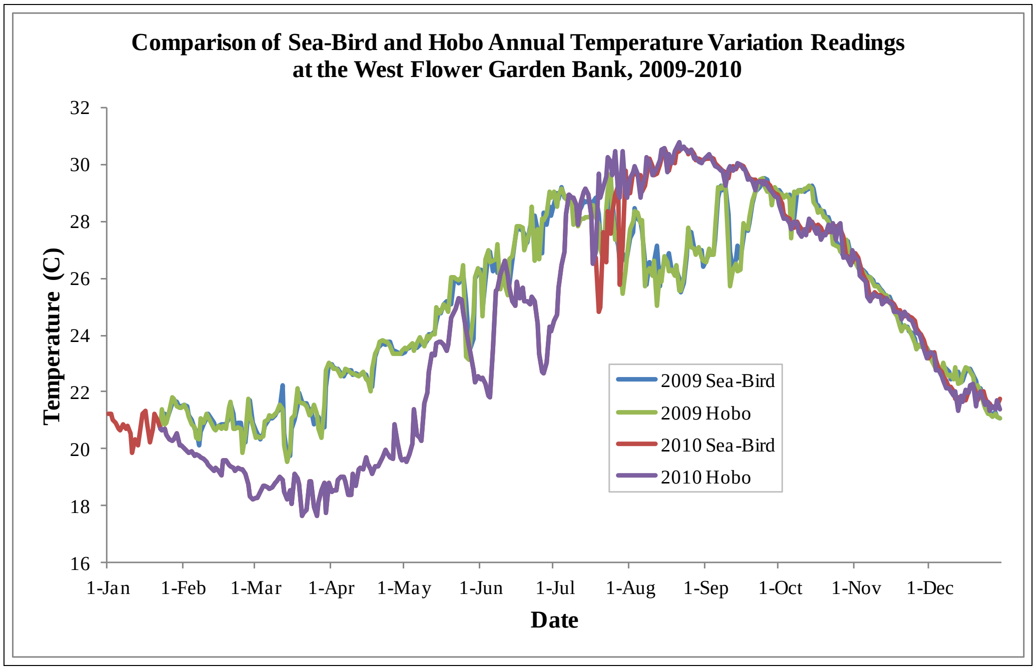


Figure 9.4.2. Comparison of Sea-Bird and Hobo daily average sea water temperature readings measured near the reef cap at the WFGB from 2009 to 2010.

9.4.1.2. Temperature

Historical long-term averages derived from past monitoring periods show that the temperature minimum on the reef cap typically occurs from January to mid-March and the temperature maximum from mid-August through mid-September (Figures 4.7.3 and 4.7.4). The temperature on the EFGB reef cap was typically slightly warmer than that on the WFGB, especially during the summer months. The may be due to the WFGB proximity to the shelf edge is more likely to subject the reef cap to cooler water. The EFGB is slightly farther up on the continental shelf, perhaps subjecting it more regularly warmer water masses. The average temperature range on the EFGB reef cap from 1990 to 2010 was 19.8 to 29.7°C. The average temperature range on the WFGB reef cap from 1990 to 2010 was 19.5 to 29.3°C.

Seasonal thermal changes over the reef caps of the EFGB and WFGB are very apparent in the Figures 9.4.3 and 9.4.4. From a winter minimum, the temperature gradually rises through the end of March and reaches a maximum during mid-August through mid-September. The temperature decreases gradually starting around October and reaches an annual minimum by mid-February through mid-March. During the 2009 to 2010 monitoring period, there were several thermal anomalies (both positive and negative), particularly in 2010. The most notable was the extreme warming that the western Atlantic region experienced during the summer of 2010. The prolonged sea surface thermal anomaly began in the summer and continued well into the fall, causing coral bleaching throughout the region.

Several thermal anomalies were recorded in 2009 and 2010 at the EFGB. When compared to historical means, the most dramatic was the very cold winter and spring temperatures experienced in March and April 2010. But there were also low summer temperatures in 2009, and a sudden decrease in temperature in late July 2010. The temperature over the reef cap was above average for several months during the summer and fall of 2010 (Figure 9.4.3). For a period of 27 days, temperature in summer 2010 exceeded the coral bleaching threshold of 30°C. During that time, temperature exceeded 30°C for 27 days. However, the monitoring cruise was completed that year before any visible bleaching.

Several thermal anomalies were also recorded at the WFGB. Below average summer temperatures occurred in 2009, and like in the EFGB, a sudden decrease in temperature occurred in late July 2010 at the WFGB. Winter and spring temperatures were also abnormally low at the WFGB in 2010. The temperature over the reef cap was high during the summer and fall of 2010 compared with the long term average (Figure 9.4.4). The summer temperature in 2010 exceeded the coral bleaching threshold of 30°C at the WFGB, as well. During that time, temperature exceeded 30°C for 24 consecutive days. Coral bleaching was observed during the 2010 cruises in October and November at the WFGB and is described in sections 3.4 and 4.3 of this report.

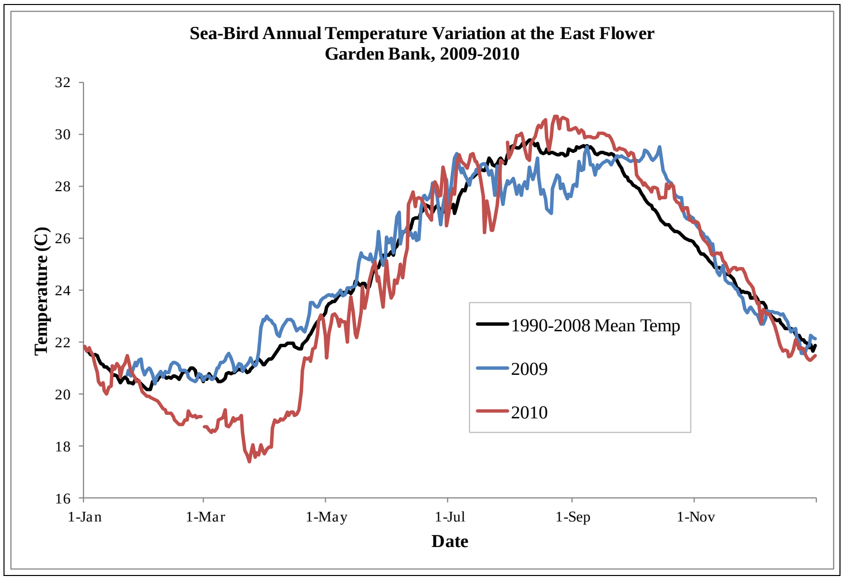


Figure 9.4.3. Sea water temperature measured using Sea-Bird datasonde near the reef cap at the EFGB in 2009 and 2010, and the historical long-term average temperature from past monitoring periods.

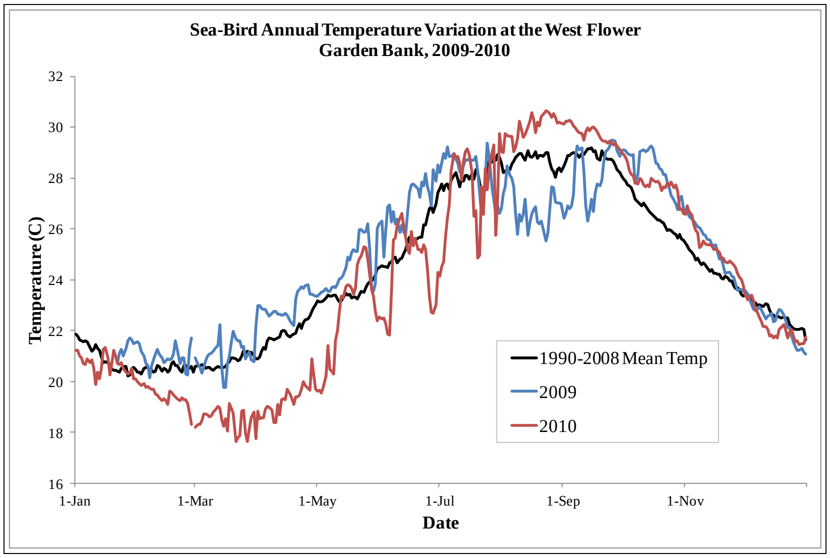


Figure 9.4.4. Sea water temperature measured using Sea-Bird datasonde near the reef cap at the WFGB in 2009 and 2010, and the historical long-term average temperature from past monitoring periods.

9.4.1.3. Salinity

Accurate salinity data were obtained from the Sea-Bird MicroCAT for January 2009 to December 2010, ranging from approximately 31 to 38 PSU at the EFGB and WFGB with a mean of approximately 36 PSU. The data indicated lower salinity in summer months, a pattern consistent on both banks. During 2009, there were two annual events of low salinity on the reef caps of the FGB: one in May/June at the EFGB and another, more pronounced event from May through August at the WFGB. During 2010, there were also two annual events of low salinity: one from May through August at the EFGB and another, more pronounced event from August through November at the WFGB. Although the data collected appear to be within the accepted limits of salinity for coral reefs located in the Western Atlantic (31–38 PSU; Coles and Jokiel 1992), the WFGB salinity data included one value below 31 PSU in June 2009.

Future salinity data collected by the Sea-Bird MicroCAT conductivity recorder should elucidate the occurrence and intensity of low salinity events on the reef cap of the FGB. For now, independent measurements of salinity at and near the FGB point to the occurrence of substantial changes of salinity. The most probable source of low salinity water at the FGB is a nearshore river-seawater mix that reaches the outer continental shelf, eminating principally from the Mississippi and Atchafalaya River watersheds, and subjecting the FGB occasionally to nearshore processes and to regional river runoff.

9.4.2. Chlorophyll *a* and Nutrients

Chl *a* concentrations in 2009 and 2010 revealed that the water column overlying the FGB reef caps could occasionally contain as much as 2.14 mg/m³. Not all water samples contained detectable levels of chl *a* (>1 mg/m³), and concentrations at the shelf edge in the northwestern Gulf of Mexico typically range from 0.1–0.3 mg/m³ (Nowlin et al. 1998). The highest values for surface chl *a* are typically expected in the summer (July–August; Nowlin et al. 1998). The relatively high values of chl *a* (by FGB standards) observed on 05/27/2010 may be indicative of an algal bloom, and coincided with a period with reduced salinity, suggesting the influence of nearshore water. There were unfortunately no oceanographic satellite data available through NOAA's CoastWatch Program to examine the occurrence of an algal bloom at the FGB in May 2009. The use of CoastWatch to monitor changes in chl *a* in the area of the FGB is certainly more useful than spot checks alone. The spot checks conducted here were valuable for ground truthing purposes and to examine vertical profiles over the reef cap.

No definitive trends could be determined from the nutrient data. Ammonia values were typically less than 1 mg/l from the sea surface to the reef cap, with the exception of samples taken on 07/07–08/2009 at the EFGB and WFGB. Nitrate levels were typically very low (less than 0.15 mg/l) even when relatively high chlorophyll a was measured. TKN (organic nitrogen and ammonia) was detected in all water samples collected at the banks in 2009, with concentrations ranging from 0.84–13.9 mg/l (above the 0.10 mg/l detection limit). Only about 10% of the samples from 2010 contained TKN concentrations above detectable limits. Soluble reactive phosphorous was not detected. After the *Deepwater Horizon* oil spill in 2010, TPH concentrations were undetectable in all water samples collected at the FGB, a result that is consistent with the measured trajectories of oil from the incident.

The data gathered here could not elucidate annual patterns of nutrient concentrations at the FGB. Nowlin et al. (1998) showed that shelf edge waters in the northwestern Gulf of Mexico are typically stripped of nutrients. When present, the probable sources of nutrients in the water column at the FGB are nearshore waters (Nowlin et al. 1998), sediments (Entsch et al. 1983), or benthic and planktonic organisms (D'Elia and Wiebe 1990). More frequent sampling is required to understand nutrient dynamics over the reef caps.

9.4.3. Sea State

During the course of the 2009 to 2010 monitoring period, three tropical storms and two hurricanes occurred in the Gulf of Mexico. In the past, up to 11 tropical cyclones have affected the Gulf of Mexico in one year (Precht et al. 2006). In 2008, Hurricane Ike crossed over the EFGB (eventually made landfall in Galveston, Texas), damaging coral in the long-term monitoring study site. However, the 2009 and 2010 storms were located in other areas of the Gulf of Mexico and did not impact the FGBNMS. Hurricane Ida in 2009 and Tropical Storm Bonnie in 2010 were the two cyclones that came closest to the FGB during the monitoring period (Figure 9.4.5). Table 9.4.1 lists all of the tropical cyclones that have occurred in the Gulf of Mexico since 2002.

Table 9.4.1.

List of Tropical Cyclones that Entered the Gulf of Mexico from 2002 to 2010

Source data: NOAA, National Hurricane Center (2010). Cat=category.

Name	Date	Wind Speed (mph) or Category	Location and Distance
Tropical Storm Bertha	8/4/02	40	Northeast GOMEX, ~ 250 km north of the FGB
Tropical Storm Edouard	9/1/02	65	Northeast GOMEX, ~500 km east of the FGB
Tropical Storm Fay	9/7/02	60	Northwest GOMEX, ~100 km west of the FGB
Tropical Storm Hanna	9/12/02	50	Passed more than 400 km east of the FGB
Tropical Storm Bill	6/29/03	60	Passed within 200 km east of the FGB
Tropical Storm Grace	8/30/03	40	Passed within 100 km of the FGB
Tropical Storm Henri	9/3/03	50	Passed 700 km to the east of the FGB
Tropical Storm Larry	10/2/03	60	Took place in the southern GOMEX
Tropical Storm Bonnie	08/10/04	50	Central GOMEX, ~401 km (249 mi) east of the EFGB
Hurricane Charley	08/13/04	Cat 4	Florida Straits, ~1132 km (703 mi) from the EFGB
Tropical Storm Frances	09/04/04	65	Northeast GOMEX, ~924 km (574 mi) east of the EFGB
Hurricane Ivan	09/15/04	Cat 4	FGB Eastern GOMEX, ~168 km (104 mi) east of the EFGB
Tropical Storm Matthew	10/09/04	40	Northwest GOMEX, ~191 km (119 mi) east of the EFGB
Tropical Storm Arlene	06/11/05	69	GB Central GOMEX, ~635 km (395 mi) east of the EFGB
Tropical Storm Bret	06/25/05	40	Southwest GOMEX, ~805 km (500 mi) southwest of the WFGB
Tropical Storm Cindy	07/05/05	70	Central GOMEX, ~307 km (191 mi) east of the EFGB
Hurricane Dennis	07/10/05	Cat 4	Central GOMEX, ~686 km (426 mi) east of the EFGB
Hurricane Emily	07/19/05	Cat 1	Southwest GOMEX, ~437 km (272 mi) south of the WFGB
Tropical Storm Gert	07/25/05	45	Southwest GOMEX, ~924 km (574 mi) south of the WFGB
Tropical Storm Jose	08/23/05	50	Central GOMEX, ~394 km (245 mi) east of the EFGB
Hurricane Katrina	08/28/05	Cat 5	Central GOMEX, ~394 km (245 mi) east of the EFGB
Hurricane Rita	09/23/05	Cat 3	Central GOMEX, ~93 km (58 mi) east of the EFGB
Tropical Storm Stan	10/3/2005	40	Southwest GOMEX, ~862 km (535 mi) south of the EFGB
Hurricane Wilma	10/24/05	Cat 3	Southeast GOMEX, ~965 km (600 mi) southeast of the EFGB
Tropical Storm Alberto	06/12/06	69	Eastern GOMEX, ~659 km (409 mi) southeast of the EFGB
Tropical Storm Barry	06/02/07	58	Southeast GOMEX,~926 km (576 mi)

Name	Date	Wind Speed (mph) or Category	Location and Distance
			southeast of the EFGB
Tropical Storm Erin	08/15/07	40	Western GOMEX, ~216 km (134 mi) east of the WFG
Hurricane Humberto	09/13/07	Cat 1	Northwest GOMEX, ~123 km (76 mi) west of the WFGB
Hurricane Lorenzo	09/25/07	Cat 1	Southwest GOMEX, 680 km (423 mi) southwest of the WFGB
Hurricane Dolly	07/22/08	Cat 1	South central GOMEX, ~360 km (224 mi) southeast of the WFGB
Tropical Storm Edouard	08/05/08	63	Central GOMEX, ~139 km (86 mi) northeast of the EFGB
Tropical Storm Fay	08/23/08	45	Eastern GOMEX, ~512 km (318 mi) east of the EFGB
Hurricane Gustav	09/01/08	Cat 3	East central GOMEX, ~300 km (186 mi) east of the EFGB
Hurricane Ike	09/13/08	Cat 2	Central GOMEX, ~0.7 km (0.4 mi) from the EFGB
Tropical Storm Marco	10/07/08	63	Southwest GOMEX, ~916 km (569 mi) south of the WFGB
Tropical Storm Claudette	8/16/2009	60	Eastern GOMEX, ~1,207 km (750 mi) southeast of the EFGB
Hurricane Ida	11/11/2009	Cat 2	Central GOMEX, ~450 km (280 mi) northeast of the EFGB
Hurricane Alex	6/30/2010	Cat 2	Southwest GOMEX, ~482 km (300 mi) southwest of the WFGB
Tropical Storm Bonnie	7/24/2010	45	Eastern GOMEX, ~402 km (250 mi) southeast of the EFGB
Tropical Storm Hermine	9/5/2010	70	Southwest GOMEX, ~467 km (290 mi) southwest of the WFGB

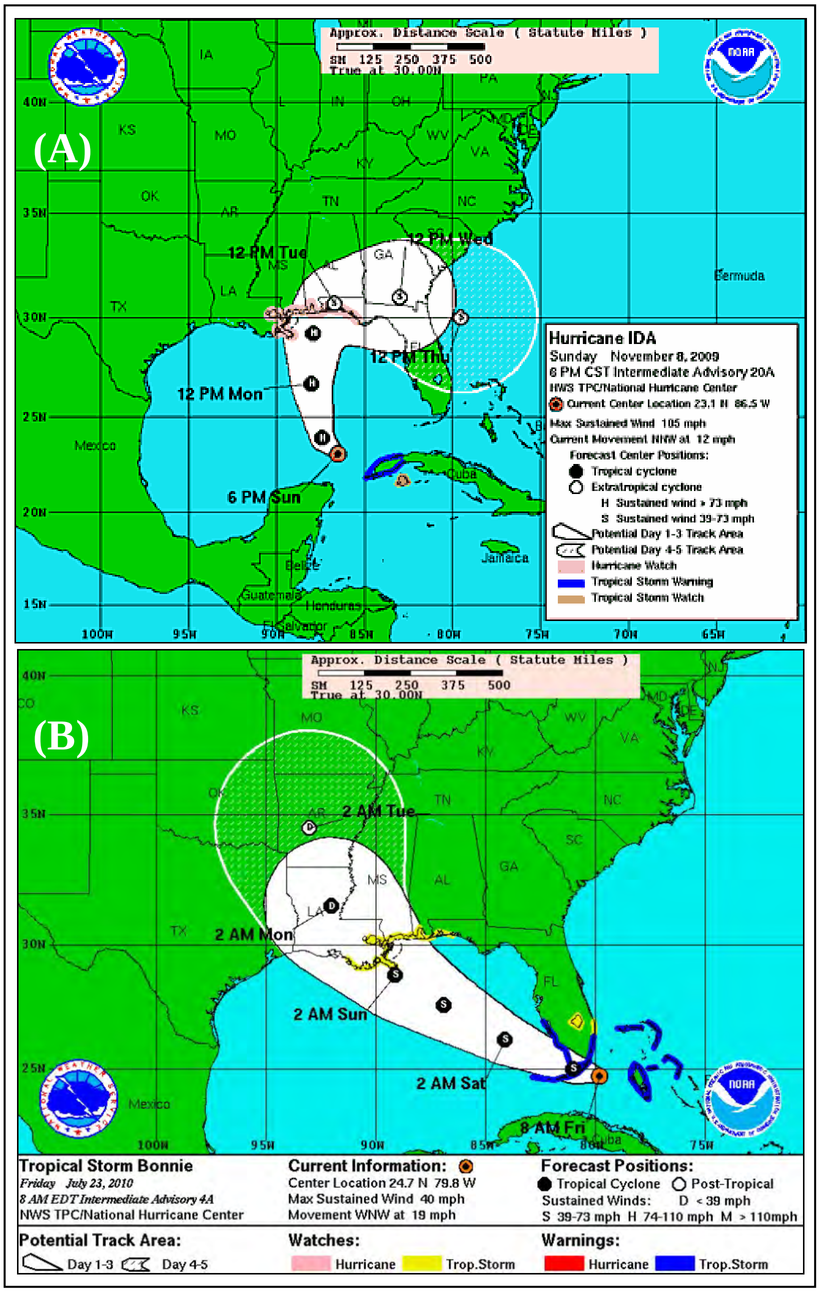


Figure 9.4.5. Hurricane Ida (A) and Tropical Storm Bonnie (B) storm track areas (NOAA Hurricane Center).

CHAPTER 10.0: FISH SURVEYS

10.1. FISH SURVEYS METHODOLOGICAL RATIONALE

Surveys of fish assemblages have been conducted at the FGBNMS since the early 1980s; however, these surveys have not generally been part of the long-term monitoring study (Boland et al. 1983; Rezak et al. 1985; Dennis and Bright 1988; Pattengill 1998). Fish surveys were officially added to the long-term monitoring protocol in 2002.The fish assemblages of the coral reef zone at the EFGB and WFGB are primarily composed of Caribbean reef species; however, the total number of species is lower in comparison. Certain families such as the snappers (Lutjanidae) and grunts (Haemulidae) are underrepresented at the FGB mainly due to lack of diverse and nearby seagrass and mangrove habitats (Jones and Clark 1981; Lukens 1981; Rezak et al. 1985; Mumby et al. 2004). The influence of nearby offshore gas and petroleum production platforms on fish assemblages at the FGBNMS has been under continuous investigation (Rooker et al. 1997). Therefore, continued monitoring of the FGBNMS is vital to increasing our understanding of this unique habitat in light of the ongoing, as well as the changing, natural and anthropogenic pressures on fish populations.

10.2. FISH SURVEYS FIELD METHODS

Twenty-four stationary visual fish surveys were conducted at each bank in 2009. In 2010, 25 surveys were conducted on the reef cap at the EFGB, and 26 were conducted at the WFGB (a minimum of six in each quadrant of the study sites). Fishes were visually assessed using SCUBA and a stationary visual census technique (Bohnsack and Bannerot 1986). Observations of fishes were restricted to an imaginary cylinder with a radius 7.5 m (24.6 ft) from the diver, extending to the surface. All fish species observed within the first five minutes of the survey were recorded as the diver slowly rotated in place. Immediately following this five-minute observation period, one rotation was conducted for each species noted in the original five-minute period to record abundance (number of individuals per species) and total length (within eight categories). Transitory or schooling species were counted and measured at the time the individuals moved through the cylinder during the initial five-minute period. After the initial five-minute period, no additional species were added. Each survey required 10 to 15 minutes.

For each quadrant, a random number was generated between 0 and 50 to indicate the starting location along the first boundary line encountered (e.g., if the random number is 27 and the corner of the transect tape is 0, the transect is started at 27 m along the transect tape, and if the lowest corner of the transect tape is 50, the transect is started at 77 m along the transect tape). A second random number was generated between 0 and 40 to determine the number of fin kicks perpendicular from the boundary line into the study site. It is assumed that it takes 40 fin kicks to swim 50 m if there is not a strong current. Those criteria provided the location for the first fish count. Subsequent survey starting points were determined with a second set of randomly generated numbers with the first number providing a heading, between 0^o and 360^o, and the second providing the number

of fin kicks, between 12 and 40, to ensure the starting point was at least 15 m away from the previous location. A third number was generated to provide a random heading, between 0° and 360°, in which to lay the tape marking the 7.5 m radius of the survey.
Fish survey dives began in the early morning (after 0700), and were repeated by two to three divers throughout the day until dusk. Survey locations were spread randomly within the 100 x 100 m study site. Survey depths ranged from 20–24 m (65–80 ft).

10.3. FISH SURVEY DATA AND STATISTICAL ANALYSIS

Fish densities are expressed as the number of fish per 100 m². For each bank and year, densities were calculated by dividing the mean number of individuals per survey by the horizontal area of the survey cylinder (176.7 m²). This value was then multiplied by 100 to provide fish densities per 100 m².

Percent sighting frequency for each species is expressed as the percentage of the total number of times the species was recorded out of the total number of surveys for the site (bank and year). Species richness is the total number of species for each site (bank and year). Relative abundance is expressed as the number of individuals of one species divided by the total number of all species observed.

Size-frequency distributions for four trophic guilds (herbivores, piscivores, invertivores, and planktivores) were calculated for each bank and year by dividing the number of herbivores, piscivores, invertivores, and planktivores in each size class by the total number observed in each trophic guild. Size classes included <5 cm, 5–10 cm, 10–15 cm, 15–20 cm, 20–25 cm, 25–30 cm, 30–35 cm and >35 cm. The herbivore guild is comprised of *Acanthuridae, Blennidae, Kyphosidae, Scaridae*, and members of the *Balistidae* (Black Durgon), *Gobiidae* (Goldspot Goby), *Pomacanthidae* (Queen Angelfish), and *Pomacentridae* (Cocoa, Bi-Color, Yellowtail, and Dusky Damselfish) families. The piscivore guild is comprised of *Aulostomidae*, *Carangidae, Inermiidae, Muraenidae, Sphyraenidae,* and members of the *Lutjanidae* (Dog Snapper), and *Serranidae* (Yellowmouth, Tiger, Black, and Yellowfin Groupers, Graysby, and Scamp) families. The invertivore guild is comprised of *Apogonidae, Chaetodontidae, Cirrhitidae, Dasyatidae, Diodontidae, Holocentridae, Monacanthidae, Mullidae, Muraenidae, Ostraciidae, Tetraodontidae,* and members of the *Balistidae* (Ocean and Queen Triggerfish), *Gobiidae* (Neon Goby), *Labridae* (Spanish and Spotfin Hogfish, Clown, Yellowhead, Slippery Dick, and Bluehead Wrasse, and Pudding Wife), *Lutjanidae* (Grey Snapper), and *Pomacanthidae* (Rock Beauty and French Angelfish), *Pomacentridae* (Brown Chromis, Sergeant Major, and Three-Spot Damselfish), and *Serranidae* (Rock and Red Hinds, and Coney) families. The planktivore guild is comprised of *Echeneidae*, and members of the *Labridae* (Creole Wrasse), *Pomacentridae* (Blue Chromis, Purple Reeffish, and Sunshinefish), and *Serranidae* (Creolefish) families.

Diversity was calculated using the Shannon-Wiener diversity index, H':

$$H' = -\sum_{i=1}^{k} p_i \log p_i$$

where k is the number of species present and p_i is the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals observed. Species evenness (J') was determined for each site and year using the following calculation:

$$J' = \frac{H'}{H'_{\max}}$$

where $H'_{\max}$ was the maximum possible diversity ($H'_{\max}$ = log k).

To allow the valid application of parametric analyses of variance, fish abundances were $\log_{10}$+1 transformed to make them normal, homoscedastic, and additive (Zar 1984; Aronson et al. 1994; Edmunds and Carpenter 2001). Two-sample t-tests (two-tailed) were used to compare densities and species-richness values by bank and year. In addition, observations of manta rays were removed from all statistical and biomass analyses due to their rare nature.

Percent sighting frequency for each species was expressed as the percentage of the total number of times the species was recorded out of the total number of surveys for the site (bank). Species richness is the number of species recorded at each site (bank). Fish abundances were $\log_{10}$+1 transformed as mentioned above and two-sample t-tests (two-tailed) were used to compare the fish abundances and species richness by bank. Size frequency distributions for the herbivores, piscivores, invertivores, and planktivores were as described in the previous section.

Fish biomass, an important aspect of coral reef ecology, was computed by converting length data to weights using the allometric length-weight conversion formula:

$$W = \alpha * L^{\beta}$$

where W = individual weight (grams), L = length of fish (cm), and α and β are constants for each species generated from the regression of its length and weight, derived from FishBase (2009) and Bohnsack and Harper (1988). Because lengths for every individual fish were not recorded, mean lengths for each species size categories were used. A species-biomass per unit area estimate (g/m^2) was calculated by dividing the mean biomass for a species across all surveys by the area of a diver survey (176.7 m^2). Coupling both biomass and abundance was useful in assessing the fish communities at the EFGB and WFGB.

All comparisons of density or biomass were conducted using parametric models on log(n+1) transformed means (either ANOVAs or two-tailed t-tests, unless otherwise stated). Species prevalence was determined by calculating the presence/absence of each species in each survey and summing across surveys. Tests of differences in prevalence of species between banks were performed using proportions tests based on binomial distributions. All tests were conducted using JMP9® statistical software package.

The NOAA National Centers for Coastal Ocean Science (NCCOS) BioGeography Branch conducted annual fish and benthic community structure surveys at EFGB and WFGB in 2006, 2007, 2009, and 2010. These surveys are conducted randomly on the entire coral cap in high relief and low relief habitats, and couple fish abundance data with benthic communities. Fish species abundance, size and distribution were characterized using 75 belt transect surveys, showing that density and biomass and species richness were higher at WFGB than EFGB. Additional information can be found at the NCCOS website (http://ccma.nos.noaa.gov/ecosystems/sanctuaries/ fgb_nms).

10.4. FISH SURVEYS RESULTS

Fish surveys were conducted at both banks during 2009 and 2010. In 2009, fish surveys were conducted in August at both the EFGB and WFGB. In 2010, fish surveys were conducted in August at the EFGB. For the WFGB, several surveys were completed in August, but due to inclement weather, the remaining surveys were collected in October. Table 10.4.1 shows a complete list of species and their abundance per year per bank.

Table 10.4.1.

Complete Fish Species List, Rrophic Guilds, and Counts per Year per Bank

P=Piscivore, I=Invertivore, PL=Planktivore, and H=Herbivore

		EFGB		**WFGB**	
Species Name	**Trophic Guild**	**2009**	**2010**	**2009**	**2010**
Lutjanidae: *Lutjanus jocu* (Snapper, Dog)	P	8	0	0	5
Pomacentridae: *Chromis multilineata* (Chromis, Brown)	I	2532	1451	1815	1512
Serranidae: *Paranthias furcifer* (Creolefish)	PL	923	760	570	1177
Labridae: *Thalassoma lucasanum* (Wrasse, Bluehead)	I	748	283	566	283
Pomacentridae: *Stegastes planifrons* (Damselfish, Three-spot)	I	141	71	157	55
Pomacentridae: *Stegastes variabilis* (Damselfish, Cocoa)	H	29	69	40	83
Serranidae: *Mycteroperca interstitialis* (Grouper, Yellowmouth)	P	12	6	4	6
Kyphosidae: *Kyphosus incisor* / *Kyphosus sectatrix* (Chub)	H	354	64	18	49
Scaridae: *Scarus vetula* (Parrotfish, Queen)	H	54	71	56	68
Cirrhitidae: *Amblycirrhitus pinos* (Hawkfish, Redspotted)	I	3	1	3	3

		EFGB		WFGB	
Species Name	**Trophic Guild**	**2009**	**2010**	**2009**	**2010**
Pomacentridae: *Stegastes partitus* (Damselfish, Bi-color)	H	364	132	235	82
Acanthuridae: *Acanthurus coeruleus* (Tang, Blue)	H	120	83	140	64
Atherinopsidae: *Menidiinae* sp. (Silversides)	H	910	0	0	0
Pomacentridae: *Chromis cyanea* (Chromis, Blue)	PL	525	40	449	134
Tetraodontidae: *Canthigaster rostrata* (Puffer, Sharpnose)	I	106	79	125	91
Labridae: *Clepticus parrae* (Wrasse, Creole)	PL	1710	291	542	361
Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	H	11	3	11	3
Pomacanthidae: *Holacanthus ciliaris* (Angelfish, Queen)	H	3	0	5	2
Labridae: *Bodianus rufus* (Hogfish, Spanish)	I	48	63	85	90
Blenniidae: *Ophioblennius macclurei* (Blenny, Redlip)	H	27	0	39	4
Chaetodontidae: *Chaetodon ocellatus* (Butterflyfish, Spotfin)	I	9	0	8	8
Pomacentridae: *Chromis scotti* (Reeffish, Purple)	PL	139	23	240	81
Scaridae: *Sparisoma aurofrenatum* (Parrotfish, Redband)	H	53	25	10	13
Serranidae: *Mycteroperca tigris* (Grouper, Tiger)	P	4	7	0	11
Pomacentridae: *Microspathodon chrysurus* (Damselfish, Yellowtail)	H	16	19	33	7
Pomacanthidae: *Holacanthus tricolor* (Angelfish, Rock Beauty)	I	19	5	11	1
Chaetodontidae: *Chaetodon sedentarius* (Butterflyfish, Reef)	I	17	29	23	36
Monacanthidae: *Cantherhines pullus* (Filefish, Orange Spotted)	I	6	1	4	0
Pomacentridae: *Chromis insolata* (Sunshinefish)	PL	104	7	42	15
Scaridae: *Sparisoma viride* (Parrotfish, Stoplight)	H	23	38	51	30
Carangidae: *Caranx latus* (Jack, Horse-eye)	P	83	0	17	5
Carangidae: *Caranx lugubris* (Jack, Black)	P	5	5	10	0
Balistidae: *Canthidermis sufflamen* (Triggerfish, Ocean)	I	4	2	3	0
Serranidae: *Cephalopholis cruentata* (Graysby)	P	12	17	15	19
Ostraciidae: *Lactophrys triqueter* (Trunkfish, Smooth)	I	5	10	9	5
Labridae: *Halichoeres maculipinna* (Wrasse, Clown)	I	14	0	49	3
Acanthuridae: *Acanthurus bahianus* (Surgeonfish, Ocean)	H	9	24	6	15
Balistidae: *Melichthys niger* (Durgon, Black)	H	12	23	39	30
Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	I	9	5	27	15
Gobiidae: *Elacatinus oceanops* (Goby, Neon)	I	3	11	2	2
Sphyraenidae: *Sphyraena barracuda* (Barracuda, Great)	P	6	47	18	75
Mobulidae: *Manta birostris* (Ray, Manta)	PL	1	1	0	0
Serranidae: *Mycteroperca bonaci* (Grouper, Black)	P	1	0	0	1

		EFGB		WFGB	
Species Name	**Trophic Guild**	**2009**	**2010**	**2009**	**2010**
Pomacanthidae: *Pomacanthus paru* (Angelfish, French)	I	8	7	1	1
Scaridae: *Scarus taeniopterus* (Parrotfish, Princess)	H	5	34	1	17
Serranidae: *Epinephelus adscensionis* (Hind, Rock)	I	2	2	0	0
Serranidae: *Epinephelus guttatus* (Hind, Red)	I	1	0	0	0
Serranidae: *Mycteroperca phenax* (Scamp)	P	2	1	1	0
Labridae: *Halichoeres garnoti* (Wrasse, Yellowhead)	I	8	4	18	19
Mullidae: *Pseudupeneus maculatus* (Goatfish, Spotted)	I	2	0	0	0
Inermiidae: *Emmelichthyops atlanticus* (Bonnetmouth)	P	2510	0	12	0
Ostraciidae: *Acanthostracion polygonius* (Cowfish, Honeycomb)	I	1	1	4	0
Echeneidae: *Echeneidae* sp. (Remora)	PL	2	0	0	0
Chaetodontidae: *Prognathodes aculeatus* (Butterflyfish, Longsnout)	I	2	4	11	7
Pomacentridae: *Stegastes adustus* (Damselfish, Dusky)	H	5	7	16	4
Scaridae: *Sparisoma atomarium* (Parrotfish, Greenblotch)	H	2	0	2	0
Carangidae: *Carangoides ruber* (Jack, Bar)	P	41	16	6	31
Labridae: *Bodianus pulchellus* (Hogfish, Spotfin)	I	1	0	0	0
Ostraciidae: *Lactophrys bicaudalis* (Trunkfish, Spotted)	I	1	0	3	0
Carangidae : *Caranx crysos* (Blue runner)	P	4	0	2	0
Muraenidae: *Gymnothorax meleagris* (Moray, Spotted)	P	1	0	1	1
Lutjanidae: *Lutjanus agennes* (Snapper, Grey)	I	0	5	11	5
Apogonidae: *Apogon* sp. (Cardinal fish sp.)	I	0	0	1	0
Aulostomidae: *Aulostomus maculatus* (Trumpetfish)	P	0	0	2	0
Holocentridae: *Holocentrus rufus* (Squirrelfish, Longspine)	I	0	1	4	3
Carangidae: *Elagatis bipinnulata* (Rainbow runner)	P	0	0	100	0
Diodontidae: *Diodon holocanthus* (Ballonfish)	I	0	0	1	1
Monacanthidae: *Cantherhines macrocerus* (Filefish, Whitespotted)	I	0	1	2	0
Mullidae: *Mulloidichthys martinicus* (Goatfish, Yellow)	I	0	3	9	0
Gobiidae: *Gnatholepis thompsoni* (Goby, Goldspot)	H	0	0	1	0
Muraenidae: *Gymnothorax miliaris* (Moray, Goldentail)	I	0	0	1	0
Dasyatidae: *Dasyatis americana* (Stingray, Southern)	I	0	0	1	0
Labridae: *Halichoeres radiatus* (Pudding wife)	I	0	2	2	0
Labridae: *Halichoeres bivittatus* (Wrasse, Slippery Dick)	I	0	0	0	11
Scaridae: *Scarus iseri* (Parrotfish, Striped)	H	0	5	0	2
Tetraodontidae: *Sphoeroides spengleri* (Puffer, Bandtail)	I	0	0	0	0
Chaetodontidae: *Chaetodon striatus* (Butterflyfish, Banded)	I	0	1	0	1

		EFGB		WFGB	
Species Name	**Trophic Guild**	**2009**	**2010**	**2009**	**2010**
Balistidae: *Balistes vetula* (Triggerfish, Queen)	I	0	2	0	0
Serranidae: *Liopropoma rubre* (Bass, Peppermint)	I	0	1	0	0
Lutjanidae: *Lutjanus argentiventris* (Snapper, Yellowtail)	PL	0	0	0	0
Holocentridae: *Holocentrus adscensionis* (Squirrelfish)	I	0	0	0	0
Serranidae: *Cephalopholis fulva* (Grouper, Coney)	I	0	0	0	0
Serranidae: *Mycteroperca venenosa* (Grouper, Yellowfin)	P	0	0	0	0

During the 2009 and 2010 monitoring period, 99 Bohnsack and Bannerot visual fish census surveys were conducted at each bank. The highest number conducted during a single sampling effort was 26, at the WFGB in 2010. The smallest number was 24, at both banks in 2009. Each survey represents one sample. The long-term monitoring at the EFGB and WFGB SOW requires a minimum of 24 samples to be collected at each Bank per year. Each sample covered 176.7 m^2, resulting in an coverage of just under 44% of the 100 m x100 m study sites during 2009 and 2010 (Table 10.4.2).

Table 10.4.2.

Summary of Fish Surveys at the EFGB and WFGB in 2009 and 2010

	EFGB 2009	EFGB 2010	WFGB 2009	WFGB 2010
Number Samples (n)	24	25	24	26
% area of study site sampled	42	44	42	46
Fish cylinder samples area (m^2)	176.7	176.7	176.7	176.7
Area sampled (m^2)	4240.8	4417.5	4240.8	4594.2
Total Fish Abundance	12188	3863	5690	4547

An average of 11.71 ± 1.78 fish families per survey (sample) were recorded at the WFGB in 2009, while an average of 9.42 ± 1.86 per survey were recorded in 2010 (See Table 10.4.3). A mean of 23 ± 3.56 fish families were observed per year and bank.

Mean species richness on the banks (number of species recorded) was 57 ± 5.89 based on samples collected in 2009 and 2010. A total of 78 species were recorded in all surveys combined. The highest species richness per survey was recorded at the WFGB in 2009 (22.08 ± 2.00), and the lowest was at the WFGB in 2010 (17.42 ± 4.04) (See Table 10.4.3). When species richness was compared using a two-way ANOVA, a significant difference was observed between years ($\alpha=0.005$, P-value<0.0001), but not between banks. However, a significant interaction exists between the two factors ($\alpha=0.005$, P-value=0.0209). Analysis with Students t-test showed a significant difference in species richness between the EFGB and WFGB in 2009 ($\alpha=0.005$, P-value=0.0088), but not in

2010. A significant difference was also observed between 2009 and 2010 at both the EFGB (α=0.005, P-value=0.0425) and WFGB (α=0.005, P-value= <.0001).

The highest average fish density (number per 100 m^2) was observed at the EFGB in 2009 (490.79 ± 397.02), and the lowest average was at the EFGB in 2010 (154.52 ± 54.68) (Table 10.4.3). The high fish density value at EFGB in 2009 was primarily due to an abundance of Bonnetmouth (*Emmelichthyops atlanticus*), Silversides (*Menidiinae* sp.), Creole Wrasse (*Clepticus parrae*), and Brown Chromis (*Chromis multilineata*) (mean densities of 59.19, 21.46, 40.32, and 59.71 per 100 m^2 respectively) (Table 10.4.3). Variations in species abundance between years and banks are predominantly attributed to the presence or absence of dense schooling fish species, such as Bonnetmouth (*Emmelichthyops atlanticus*) and Silversides (*Menidiinae* sp.), that typically consist of 100's of individuals. When a two-way ANOVA is run of the log (n+1) transformed fish density data, a significant difference is seen between years (α=0.005, P-value<0.0001), and between banks (α=0.005, P-value=0.0294) and a significant interaction exists between the two factors (α=0.005, P-value=0.0.0147). In a Students t-test, a significant difference in fish density was observed between the EFGB and WFGB in 2009 (α=0.005, P-value=0.0047), but not in 2010. Both the EFGB and WFGB showed a significant difference in fish densities between 2009 and 2010 (α=0.005, P-value<0.0001 and P-value=0.0088 respectively).

Table 10.4.3.

Species and Family Richness and Fish Density for the EFGB and WFGB in 2009 and 2010

Values are expressed as richness or abundance ± SD

	EFGB 2009	**EFGB 2010**	**WFGB 2009**	**WFGB 2010**
Species Richness	61	53	63	51
Family Richness	25	20	27	20
Total Fish Abundance	12188	3863	5690	4547
Mean Abundance/Survey	490.79 (±397.02)	154.52 (±54.68)	237.08 (±84.47)	174.88 (±101.81)
Mean Abundance/100m^2 (Density)	275.9	87.4	134.2	99.0
Mean Species Richness/Survey	19.96 (±3.34)	18.24 (±2.47)	22.08 (±2.00)	17.42 (±4.04)
Mean Species Richness/m^2	0.11	0.10	0.12	0.10
Mean Family Richness	10.46 (±1.77)	9.92 (±1.47)	11.71 (±1.78)	9.42 (±1.86)
Mean Family Richness/m^2	0.06	0.06	0.07	0.05

Fish abundance varied between years and banks. Brown Chromis (*Chromis multilineata*) were the most abundant fish at both banks for both years. Other high-ranked species included Bonnetmouth (*Emmelichthyops atlanticus*), Creole Wrasse (*Clepticus parrae*), and Silversides (*Menidiinae* sp.) (Table 10.4.4).

Table 10.4.4.

Mean Fish Abundance for the EFGB and WFGB in 2009 and 2010 for Dominant Species

	Mean Abundance/100 m^2 (Density)			
Species	**EFGB 2009**	**EFGB 2010**	**WFGB 2009**	**WFGB 2010**
Bonnetmouth	59.19	0.00	0.28	0.00
Silversides	21.46	0.00	0.00	0.00
Creole Wrasse	40.32	6.59	12.78	7.86
Brown Chromis	59.71	32.85	42.80	32.91

10.4.1. Sighting Frequency and Occurrence

For the various trophic guilds at the FGB (Piscivore, Invertivore, Plankivore, and Herbivore), the percent sighting frequency (the percentage of times in which the species was observed) varied between year and Bank. The most frequently sighted species was Creolefish (*Paranthias furcifer*), sighted in 95% of surveys from 2009 to 2010 at both banks. Other top-ranked species included Bluehead Wrasse (*Thalassoma lucasanum*), Bi-color Damselfish (*Stegastes partitus*), Blue Chromis (*Chromis cyanea*), Spanish Hogfish (*Bodianus rufus*), Creole Wrasse (*Clepticus parrae*), Brown Chromis (*Chromis multilineata*), Blue Tang (*Acanthurus coeruleus*), and Sharpnose Puffer (*Canthigaster rostrata*) with sighting frequencies ranging from 74% to 94% (Table 10.4.5)

Table 10.4.5.

Percent Sighting Frequency for Species by Year and Bank, Including a Percent Sighting Frequency for All Surveys Conducted during the 2009 to 2010 Reporting Period

P=Piscivore, I=Invertivore, PL=Plankivore, and H=Herbivore

Species	**Trophic Guild**	**EFGB**		**WFGB**		**% of Total Surveys Sighted**
		2009	**2010**	**2009**	**2010**	
Lutjanidae: *Lutjanus jocu* (Snapper, Dog)	P	20.8	0.0	0.0	15.4	9.1
Pomacentridae: *Chromis multilineata* (Chromis, Brown)	I	91.7	92.0	87.5	88.5	89.9
Serranidae: *Paranthias furcifer* (Creolefish)	PL	95.8	96.0	100.0	88.5	94.9
Labridae: *Thalassoma lucasanum* (Wrasse, Bluehead)	I	95.8	96.0	95.8	88.5	93.9
Pomacentridae: *Stegastes planifrons* (Damselfish, Three-spot)	I	70.8	60.0	87.5	50.0	66.7
Pomacentridae: *Stegastes variabilis* (Damselfish, Cocoa)	H	29.2	60.0	45.8	69.2	51.5

Species	**Trophic Guild**	**EFGB**		**WFGB**		**% of Total Surveys Sighted**
		2009	**2010**	**2009**	**2010**	
Serranidae: *Mycteroperca interstitialis* (Grouper, Yellowmouth)	P	37.5	24.0	16.7	19.2	24.2
Kyphosidae: *Kyphosus incisor* / *Kyphosus sectatrix* (Chub)	H	70.8	48.0	41.7	42.3	50.5
Scaridae: *Scarus vetula* (Parrotfish, Queen)	H	70.8	72.0	83.3	76.9	75.8
Cirrhitidae: *Amblycirrhitus pinos* (Hawkfish, Redspotted)	I	12.5	4.0	12.5	11.5	10.1
Pomacentridae: *Stegastes partitus* (Damselfish, Bi-color)	H	95.8	96.0	95.8	73.1	89.9
Acanthuridae: *Acanthurus coeruleus* (Tang, Blue)	H	87.5	92.0	87.5	92.3	89.9
Atherinopsidae: *Menidiinae* sp. (Silversides)	H	8.3	0.0	0.0	0.0	2.0
Pomacentridae: *Chromis cyanea* (Chromis, Blue)	PL	95.8	60.0	91.7	69.2	78.8
Tetraodontidae: *Canthigaster rostrata* (Puffer, Sharpnose)	I	87.5	96.0	87.5	80.8	87.9
Labridae: *Clepticus parrae* (Wrasse, Creole)	PL	95.8	76.0	87.5	38.5	73.7
Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	H	25.0	8.0	12.5	7.7	13.1
Pomacanthidae: *Holacanthus ciliaris* (Angelfish, Queen)	H	12.5	0.0	16.7	3.8	8.1
Labridae: *Bodianus rufus* (Hogfish, Spanish)	I	70.8	80.0	91.7	96.2	84.8
Blenniidae: *Ophioblennius macclurei* (Blenny, Redlip)	H	37.5	0.0	54.2	11.5	25.3
Chaetodontidae: *Chaetodon ocellatus* (Butterflyfish, Spotfin)	I	20.8	0.0	16.7	19.2	14.1
Pomacentridae: *Chromis scotti* (Reeffish, Purple)	PL	41.7	16.0	70.8	61.5	47.5
Scaridae: *Sparisoma aurofrenatum* (Parrotfish, Redband)	H	45.8	44.0	25.0	23.1	34.3
Serranidae: *Mycteroperca tigris* (Grouper, Tiger)	P	16.7	24.0	0.0	30.8	18.2
Pomacentridae: *Microspathodon chrysurus* (Damselfish, Yellowtail)	H	50.0	36.0	62.5	19.2	41.4
Pomacanthidae: *Holacanthus tricolor* (Angelfish, Rock Beauty)	I	41.7	20.0	37.5	3.8	25.3
Chaetodontidae: *Chaetodon sedentarius* (Butterflyfish, Reef)	I	41.7	48.0	54.2	57.7	50.5
Monacanthidae: *Cantherhines pullus* (Filefish, Orange Spotted)	I	20.8	4.0	16.7	0.0	10.1
Pomacentridae: *Chromis insolata* (Sunshinefish)	PL	41.7	16.0	54.2	19.2	32.3
Scaridae: *Sparisoma viride* (Parrotfish, Stoplight)	H	50.0	68.0	79.2	38.5	58.6
Carangidae: *Caranx latus* (Jack, Horse-eye)	P	29.2	0.0	16.7	11.5	14.1

Species	Trophic Guild	EFGB		WFGB		% of Total Surveys Sighted
		2009	2010	2009	2010	
Carangidae: *Caranx lugubris* (Jack, Black)	P	16.7	8.0	29.2	0.0	13.1
Balistidae: *Canthidermis sufflamen* (Triggerfish, Ocean)	I	16.7	4.0	8.3	0.0	7.1
Serranidae: *Cephalopholis cruentata* (Graysby)	P	41.7	48.0	45.8	50.0	46.5
Ostraciidae: *Lactophrys triqueter* (Trunkfish, Smooth)	I	16.7	36.0	29.2	15.4	24.2
Labridae: *Halichoeres maculipinna* (Wrasse, Clown)	I	20.8	0.0	33.3	7.7	15.2
Acanthuridae: *Acanthurus bahianus* (Surgeonfish, Ocean)	H	25.0	40.0	16.7	26.9	27.3
Balistidae: *Melichthys niger* (Durgon, Black)	H	29.2	60.0	70.8	53.8	53.5
Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	I	16.7	8.0	33.3	26.9	21.2
Gobiidae: *Elacatinus oceanops* (Goby, Neon)	I	8.3	24.0	8.3	3.8	11.1
Sphyraenidae: *Sphyraena barracuda* (Barracuda, Great)	P	25.0	68.0	66.7	84.6	61.6
Mobulidae: *Manta birostris* (Ray, Manta)	PL	8.3	4.0	0.0	0.0	3.0
Serranidae: *Mycteroperca bonaci* (Grouper, Black)	P	4.2	0.0	0.0	3.8	2.0
Pomacanthidae: *Pomacanthus paru* (Angelfish, French)	I	16.7	16.0	4.2	3.8	10.1
Scaridae: *Scarus taeniopterus* (Parrotfish, Princess)	H	12.5	40.0	4.2	23.1	20.2
Serranidae: *Epinephelus adscensionis* (Hind, Rock)	I	8.3	8.0	0.0	0.0	4.0
Serranidae: *Epinephelus guttatus* (Hind, Red)	I	4.2	0.0	0.0	0.0	1.0
Serranidae: *Mycteroperca phenax* (Scamp)	P	8.3	4.0	4.2	0.0	4.0
Labridae: *Halichoeres garnoti* (Wrasse, Yellowhead)	I	12.5	8.0	29.2	30.8	20.2
Mullidae: *Pseudupeneus maculatus* (Goatfish, Spotted)	I	4.2	0.0	0.0	0.0	1.0
Inermiidae: *Emmelichthyops atlanticus* (Bonnetmouth)	P	33.3	0.0	4.2	0.0	9.1
Ostraciidae: *Acanthostracion polygonius* (Cowfish, Honeycomb)	I	4.2	4.0	16.7	0.0	6.1
Echeneidae: *Echeneidae* sp. (Remora)	PL	4.2	0.0	0.0	0.0	1.0
Chaetodontidae: *Prognathodes aculeatus* (Butterflyfish, Longsnout)	I	8.3	12.0	25.0	23.1	17.2
Pomacentridae: *Stegastes adustus* (Damselfish, Dusky)	H	8.3	12.0	33.3	7.7	15.2
Scaridae: *Sparisoma atomarium* (Parrotfish, Greenblotch)	H	4.2	0.0	4.2	0.0	2.0

Species	**Trophic Guild**	**EFGB**		**WFGB**		**% of Total Surveys Sighted**
		2009	**2010**	**2009**	**2010**	
Carangidae: *Carangoides ruber* (Jack, Bar)	P	12.5	24.0	8.3	26.9	18.2
Labridae: *Bodianus pulchellus* (Hogfish, Spotfin)	I	4.2	0.0	0.0	0.0	1.0
Ostraciidae: *Lactophrys bicaudalis* (Trunkfish, Spotted)	I	4.2	0.0	8.3	0.0	3.0
Carangidae: *Caranx crysos* (Blue runner)	P	4.2	0.0	4.2	0.0	2.0
Muraenidae: *Gymnothorax meleagris* (Moray, Spotted)	P	4.2	0.0	4.2	3.8	3.0
Lutjanidae: *Lutjanus agennes* (Snapper, Grey)	I	0.0	16.0	16.7	11.5	11.1
Apogonidae: *Apogon* sp. (Cardinal fish sp.)	I	0.0	0.0	4.2	0.0	1.0
Aulostomidae: *Aulostomus maculatus* (Trumpetfish)	P	0.0	0.0	4.2	0.0	1.0
Holocentridae: *Holocentrus rufus* (Squirrelfish, Longspine)	I	0.0	4.0	16.7	7.7	7.1
Carangidae: *Elagatis bipinnulata* (Rainbow runner)	P	0.0	0.0	4.2	0.0	1.0
Diodontidae: *Diodon holocanthus* (Ballonfish)	I	0.0	0.0	4.2	3.8	2.0
Monacanthidae: *Cantherhines macrocerus* (Filefish, Whitespotted)	I	0.0	4.0	4.2	0.0	2.0
Mullidae: *Mulloidichthys martinicus* (Goatfish, Yellow)	I	0.0	8.0	12.5	0.0	5.1
Gobiidae: *Gnatholepis thompsoni* (Goby, Goldspot)	H	0.0	0.0	4.2	0.0	1.0
Muraenidae: *Gymnothorax miliaris* (Moray, Goldentail)	I	0.0	0.0	4.2	0.0	1.0
Dasyatidae: *Dasyatis americana* (Stingray, Southern)	I	0.0	0.0	4.2	0.0	1.0
Labridae: *Halichoeres radiatus* (Pudding wife)	I	0.0	8.0	8.3	0.0	4.0
Labridae: *Halichoeres bivittatus* (Wrasse, Slippery Dick)	I	0.0	0.0	0.0	11.5	3.0
Scaridae: *Scarus iseri* (Parrotfish, Striped)	H	0.0	8.0	0.0	3.8	3.0
Tetraodontidae: *Sphoeroides spengleri* (Puffer, Bandtail)	I	0.0	4.0	0.0	3.8	2.0
Chaetodontidae: *Chaetodon striatus* (Butterflyfish, Banded)	I	0.0	4.0	0.0	0.0	1.0
Balistidae: *Balistes vetula* (Triggerfish, Queen)	I	0.0	4.0	0.0	0.0	1.0
Serranidae: *Liopropoma rubre* (Bass, Peppermint)	I	0.0	1.0	0.0	0.0	1.0
Lutjanidae: *Lutjanus argentiventris* (Snapper, Yellowtail)	PL	0.0	0.0	0.0	0.0	0.0
Holocentridae: *Holocentrus adscensionis* (Squirrelfish)	I	0.0	0.0	0.0	0.0	0.0

Species	Trophic Guild	EFGB		WFGB		% of Total Surveys Sighted
		2009	2010	2009	2010	
Serranidae: *Cephalopholis fulva* (Grouper, Coney)	I	0.0	0.0	0.0	0.0	0.0
Serranidae: *Mycteroperca venenosa* (Grouper, Yellowfin)	P	0.0	0.0	0.0	0.0	0.0

Species occurrence in samples was compared between banks in both 2009 and 2010 for all observed species using a Student's t-test (Table 10.4.6). In 2009, of 73 species observed, a significant difference was observed between the banks for 11 species. This included Dog Snapper (*Lutjanus jocu*, α=0.005, P-value=0.0218), Chub (*Kyphosus incisor*/*Kyphosus sectatrix*, α=0.005, P-value=0.0426), Purple Reeffish (Chromis scotti, α=0.005, P-value=0.0426), Tiger Grouper (*Mycteroperca tigris*, α=0.005, P-value=0.0428), Stoplight Parrotfish (*Sparisoma viride*, α=0.005, P-value=0.0353), Black Durgon (*Melichthys niger*, α=0.005, P-value=0.0032), Great Barracuda (*Sphyraena barracuda*, α=0.005, P-value=0.0031), Bonnetmouth (*Emmelichthyops atlanticus*, α=0.005, P-value=0.0103), Dusky Damselfish (*Stegastes adustus*, α=0.005, P-value=0.0346), Grey Snapper (*Lutjanus agennes*, α=0.005, P-value=0.0428), and Longspine Squirrelfish (*Holocentrus rufus*, α=0.005, P-value=0.0428). In 2010, of 63 species observed, a significant difference was observed between the banks for 8 species. This included Dog Snapper (*Lutjanus jocu*, α=0.005, P-value=0.043), Bi-Color Damselfish (*Stegastes partitus*, α=0.005, P-value=0.0243), Creole Wrasse (*Clepticus parrae*, α=0.005, P-value=0.006), Spotfin Butterflyfish (*Chaetodon ocellatus*, α=0.005, P-value=0.0221), Purple Reeffish (*Chromis scotti*, α=0.005, P-value=0.0006), Stoplight Parrotfish (*Sparisoma viride*, α=0.005, P-value=0.0349), Neon Goby (*Elacatinus oceanops*, α=0.005, P-value=0.042), and Yellowhead Wrasse (*Halichoeres garnoti*, α=0.005, P-value=0.0406).

Table 10.4.6.

Species Occurrence and Percent Sighting Frequencies in Parentheses for all Species Recorded at the FGB in 2009 and 2010

Numbers in "Both Banks", "EFGB", and "WFGB" represent the number of surveys in which the species was observed with percent sighting frequency in parentheses. "P-value" represents the probability that species occurrence is randomly distributed between Banks (Student's t-test). Statistically significant comparisons are shown in bold. NS= Not significant.

Species	**2009**				**2010**			
	Both Banks	**EFGB**	**WFGB**	**P-value**	**Both Banks**	**EFGB**	**WFGB**	**P-value**
Lutjanidae: *Lutjanus jocu* (Snapper, Dog)	5 (10)	5 (21)	-	**0.0218**	4 (8)	-	4 (15)	**0.043**
Pomacentridae: *Chromis multilineata* (Chromis, Brown)	43 (88)	22 (88)	21 (88)	NS	46 (90)	23 (92)	23 (88)	NS
Serranidae: *Paranthias furcifer* (Creolefish)	47 (96)	23 (92)	24 (100)	NS	47 (92)	24 (96)	23 (88)	NS
Labridae: *Thalassoma lucasanum* (Wrasse, Bluehead)	46 (94)	23 (92)	23 (96)	NS	47 (92)	24 (96)	23 (88)	NS
Pomacentridae: *Stegastes planifrons* (Damselfish, Three-spot)	38 (78)	17 (68)	21 (88)	NS	28 (55)	15 (60)	13 (50)	NS
Pomacentridae: *Stegastes variabilis* (Damselfish, Cocoa)	18 (37)	7 (28)	11 (46)	NS	33 (65)	15 (60)	18 (69)	NS
Serranidae: *Mycteroperca interstitialis* (Grouper, Yellowmouth)	13 (27)	9 (36)	4 (17)	NS	11 (22)	6 (24)	5 (19)	NS
Kyphosidae: *Kyphosus incisor / Kyphosus sectatrix* (Chub)	27 (55)	17 (68)	10 (42)	**0.0426**	23 (45)	12 (48)	11 (42)	NS
Scaridae: *Scarus vetula* (Parrotfish, Queen)	37 (76)	17 (68)	20 (83)	NS	38 (75)	18 (72)	20 (77)	NS
Cirrhitidae: *Amblycirrhitus pinos* (Hawkfish, Redspotted)	6 (12)	3 (12)	3 (13)	NS	4 (8)	1 (4)	3 (12)	NS
Pomacentridae:	46 (94)	23 (92)	23 (96)	NS	43 (84)	24 (96)	19 (73)	**0.0243**

Species	**2009**				**2010**			
	Both Banks	**EFGB**	**WFGB**	**P-value**	**Both Banks**	**EFGB**	**WFGB**	**P-value**
Stegastes partitus (Damselfish, Bi-color)								
Acanthuridae: *Acanthurus coeruleus* (Tang, Blue)	42 (86)	21 (84)	21 (88)	NS	47 (92)	23 (92)	24 (92)	NS
Atherinopsidae: *Menidiinae* sp. (Silversides)	2 (4)	2 (8)	-	NS	-	-	-	-
Pomacentridae: *Chromis cyanea* (Chromis, Blue)	45 (92)	23 (92)	22 (92)	NS	33 (65)	15 (60)	18 (69)	NS
Tetraodontidae: *Canthigaster rostrata* (Puffer, Sharpnose)	42 (86)	21 (84)	21 (88)	NS	45 (88)	24 (96)	21 (81)	NS
Labridae: *Clepticus parrae* (Wrasse, Creole)	44 (90)	23 (92)	21 (88)	NS	29 (57)	19 (76)	10 (38)	**0.006**
Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	9 (18)	6 (24)	3 (13)	NS	4 (8)	2 (8)	2 (8)	NS
Pomacanthidae: *Holacanthus ciliaris* (Angelfish, Queen)	7 (14)	3 (12)	4 (17)	NS	1 (2)	-	1 (4)	NS
Labridae: *Bodianus rufus* (Hogfish, Spanish)	39 (80)	17 (68)	22 (92)	NS	45 (88)	20 (80)	25 (96)	NS
Blenniidae: *Ophioblennius macclurei* (Blenny, Redlip)	22 (45)	9 (36)	13 (54)	NS	3 (6)	-	3 (12)	NS
Chaetodontidae: *Chaetodon ocellatus* (Butterflyfish, Spotfin)	9 (18)	5 (20)	4 (17)	NS	5 (10)	-	5 (19)	**0.0221**
Pomacentridae: *Chromis scotti* (Reeffish, Purple)	27 (55)	10 (40)	17 (71)	**0.0426**	20 (39)	4 (16)	16 (62)	**0.0006**
Scaridae: *Sparisoma aurofrenatum* (Parrotfish, Redband)	17 (35)	11 (44)	6 (25)	NS	17 (33)	11 (44)	6 (23)	NS
Serranidae: *Mycteroperca tigris* (Grouper, Tiger)	4 (8)	4 (16)	-	**0.0428**	14 (27)	6 (24)	8 (31)	NS

Species	2009				2010			
	Both Banks	EFGB	WFGB	P-value	Both Banks	EFGB	WFGB	P-value
Pomacentridae: *Microspathodon chrysurus* (Damselfish, Yellowtail)	27 (55)	12 (48)	15 (63)	NS	14 (27)	9 (36)	5 (19)	NS
Pomacanthidae: *Holacanthus tricolor* (Angelfish, Rock Beauty)	19 (39)	10 (40)	9 (38)	NS	6 (12)	5 (20)	1 (4)	NS
Chaetodontidae: *Chaetodon sedentarius* (Butterflyfish, Reef)	23 (47)	10 (40)	13 (54)	NS	27 (53)	12 (48)	15 (58)	NS
Monacanthidae: *Cantherhines pullus* (Filefish, Orange Spotted)	9 (18)	5 (20)	4 (17)	NS	1 (2)	1 (4)	-	NS
Pomacentridae: *Chromis insolata* (Sunshinefish)	23 (47)	10 (40)	13 (54)	NS	9 (18)	4 (16)	5 (19)	NS
Scaridae: *Sparisoma viride* (Parrotfish, Stoplight)	31 (63)	12 (48)	19 (79)	**0.0353**	27 (53)	17 (68)	10 (38)	**0.0349**
Carangidae: *Caranx latus* (Jack, Horse-eye)	11 (22)	7 (28)	4 (17)	NS	3 (6)	-	3 (12)	NS
Carangidae: *Caranx lugubris* (Jack, Black)	11 (22)	4 (16)	7 (29)	NS	2 (4)	2 (8)	-	NS
Balistidae: *Canthidermis sufflamen* (Triggerfish, Ocean)	6 (12)	4 (16)	2 (8)	NS	1 (2)	1 (4)	-	NS
Serranidae: *Cephalopholis cruentata* (Graysby)	21 (43)	10 (40)	11 (46)	NS	25 (49)	12 (48)	13 (50)	NS
Ostraciidae: *Lactophrys triqueter* (Trunkfish, Smooth)	11 (22)	4 (16)	7 (29)	NS	13 (25)	9 (36)	4 (15)	NS
Labridae: *Halichoeres maculipinna* (Wrasse, Clown)	13 (27)	5 (20)	8 (33)	NS	2 (4)	-	2 (8)	NS
Acanthuridae: *Acanthurus bahianus*	10 (20)	6 (24)	4 (17)	NS	17 (33)	10 (40)	7 (27)	NS

Species	**2009**				**2010**			
	Both Banks	**EFGB**	**WFGB**	**P-value**	**Both Banks**	**EFGB**	**WFGB**	**P-value**
(Surgeonfish, Ocean)								
Balistidae: *Melichthys niger* (Durgon, Black)	24 (49)	7 (28)	17 (71)	**0.0032**	29 (57)	15 (60)	14 (54)	NS
Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	12 (24)	4 (16)	8 (33)	NS	9 (18)	2 (8)	7 (27)	NS
Gobiidae: *Elacatinus oceanops* (Goby, Neon)	4 (8)	2 (8)	2 (8)	NS	7 (14)	6 (24)	1 (4)	**0.042**
Sphyraenidae: *Sphyraena barracuda* (Barracuda, Great)	22 (45)	6 (24)	16 (67)	**0.0031**	39 (76)	17 (68)	22 (85)	NS
Mobulidae: *Manta birostris* (Ray, Manta)	2 (4)	2 (8)	-	NS	1 (2)	1 (4)	-	NS
Serranidae: *Mycteroperca bonaci* (Grouper, Black)	1 (2)	1 (4)	-	NS	1 (2)	-	1 (4)	NS
Pomacanthidae: *Pomacanthus paru* (Angelfish, French)	5 (10)	4 (16)	1 (4)	NS	5 (10)	4 (16)	1 (4)	NS
Scaridae: *Scarus taeniopterus* (Parrotfish, Princess)	4 (8)	3 (12)	1 (4)	NS	16 (31)	10 (40)	6 (23)	NS
Serranidae: *Epinephelus adscensionis* (Hind, Rock)	2 (4)	2 (8)	-	NS	2 (4)	2 (8)	-	NS
Serranidae: *Epinephelus guttatus* (Hind, Red)	1 (2)	1 (4)	-	NS	-	-	-	-
Serranidae: *Mycteroperca phenax* (Scamp)	3 (6)	2 (8)	1 (4)	NS	1 (2)	1 (4)	-	NS
Labridae: *Halichoeres garnoti* (Wrasse, Yellowhead)	10 (20)	3 (12)	7 (29)	NS	10 (20)	2 (8)	8 (31)	**0.0406**
Mullidae: *Pseudupeneus maculatus* (Goatfish, Spotted)	1 (2)	1 (4)	-	NS	-	-	-	-
Inermiidae: *Emmelichthyops atlanticus*	9 (18)	8 (32)	1 (4)	**0.0103**	-	-	-	-

Species	**2009**				**2010**			
	Both Banks	**EFGB**	**WFGB**	**P-value**	**Both Banks**	**EFGB**	**WFGB**	**P-value**
(Bonnetmouth)								
Ostraciidae: *Acanthostracion polygonius* (Cowfish, Honeycomb)	5 (10)	1 (4)	4 (17)	NS	1 (2)	1 (4)	-	NS
Echeneidae: *Echeneidae sp.* (Remora)	1 (2)	1 (4)	-	NS	-	-	-	-
Chaetodontidae: *Prognathodes aculeatus* (Butterflyfish, Longsnout)	8 (16)	2 (8)	6 (25)	NS	9 (18)	3 (12)	6 (23)	NS
Pomacentridae: *Stegastes adustus* (Damselfish, Dusky)	10 (20)	2 (8)	8 (33)	**0.0346**	5 (10)	3 (12)	2 (8)	NS
Scaridae: *Sparisoma atomarium* (Parrotfish, Greenblotch)	2 (4)	1 (4)	1 (4)	NS	-	-	-	-
Carangidae: *Carangoides ruber* (Jack, Bar)	5 (10)	3 (12)	2 (8)	NS	13 (25)	6 (24)	7 (27)	NS
Labridae: *Bodianus pulchellus* (Hogfish, Spotfin)	1 (2)	1 (4)	-	NS	-	-	-	-
Ostraciidae: *Lactophrys bicaudalis* (Trunkfish, Spotted)	3 (6)	1 (4)	2 (8)	NS	-	-	-	-
Carangidae: *Caranx crysos* (Blue runner)	2 (4)	1 (4)	1 (4)	NS	-	-	-	-
Muraenidae: *Gymnothorax meleagris* (Moray, Spotted)	2 (4)	1 (4)	1 (4)	NS	1 (2)	-	1 (4)	NS
Lutjanidae: *Lutjanus agennes* (Snapper, Grey)	4 (8)	-	4 (17)	**0.0428**	7 (14)	4 (16)	3 (12)	NS
Apogonidae: *Apogon sp.* (Cardinal fish sp.)	1 (2)	-	1 (4)	NS	-	-	-	-
Aulostomidae: *Aulostomus maculatus* (Trumpetfish)	1 (2)	-	1 (4)	NS	-	-	-	-

Species	2009				2010			
	Both Banks	EFGB	WFGB	P-value	Both Banks	EFGB	WFGB	P-value
Holocentridae: *Holocentrus rufus* (Squirrelfish, Longspine)	4 (8)	-	4 (17)	**0.0428**	3 (6)	1 (4)	2 (8)	NS
Carangidae: *Elagatis bipinnulata* (Rainbow runner)	1 (2)	-	1 (4)	NS	-	-	-	-
Diodontidae: *Diodon holocanthus* (Ballonfish)	1 (2)	-	1 (4)	NS	1 (2)	-	1 (4)	NS
Monacanthidae: *Cantherhines macrocerus* (Filefish, Whitespotted)	1 (2)	-	1 (4)	NS	1 (2)	1 (4)	-	NS
Mullidae: *Mulloidichthys martinicus* (Goatfish, Yellow)	3 (6)	-	3 (13)	NS	2 (4)	2 (8)	-	NS
Gobiidae: *Gnatholepis thompsoni* (Goby, Goldspot)	1 (2)	-	1 (4)	NS	-	-	-	-
Muraenidae: *Gymnothorax miliaris* (Moray, Goldentail)	1 (2)	-	1 (4)	NS	-	-	-	-
Dasyatidae: *Dasyatis americana* (Stingray, Southern)	1 (2)	-	1 (4)	NS	-	-	-	-
Labridae: *Halichoeres radiatus* (Pudding wife)	2 (4)	-	2 (8)	NS	2 (4)	2 (8)	-	NS
Labridae: *Halichoeres bivittatus* (Wrasse, Slippery Dick)	-	-	-	-	3 (6)	-	3 (12)	NS
Scaridae: *Scarus iseri* (Parrotfish, Striped)	-	-	-	-	3 (6)	2 (8)	1 (4)	NS
Chaetodontidae: *Chaetodon striatus* (Butterflyfish, Banded)	-	-	-	-	2 (4)	1 (4)	1 (4)	NS
Balistidae: *Balistes vetula* (Triggerfish, Queen)	-	-	-	-	1 (2)	1 (4)	-	NS
Serranidae:	-	-	-	-	1 (2)	1 (4)	-	NS

Species	2009				2010			
	Both Banks	EFGB	WFGB	P-value	Both Banks	EFGB	WFGB	P-value
Liopropoma rubre (Bass, Peppermint)								

10.4.2. Family Density, Relative Abundance, and Richness

The families with the highest total relative abundance included the damselfishes (Pomacentridae), wrasses (Labridae), and groupers and seabasses (Serranidae) (Table 10.4.7). In 2009, damselfishes were recorded at a maximum density of 91.11 per 100 m2 at the EFGB, while the minimum density of 41.29 per 100 m2 was recorded at the EFGB in 2010. A maximum density for the wrasse family of 59.63 per 100 m2 was recoded at the EFGB in 2009, while a minimum of 14.56 per 100 m2 was recorded at the EFGB in 2010. The grouper and seabass family observed a maximum density of 26.42 per 100 m2 in 2010 at the WFGB, and a minimum density of 13.91 per 100 m2 in 2009 at the WFGB. A maximum density of 3.92 per 100 m2 was recorded for the parrotfish family at the EFGB in 2010, while a minimum density of 2.83 per 100 m2 was recorded at the WFGB in both 2009 and 2010 (Table 10.4.8, Table 10.4.9, and Table 10.4.10).

Families with the highest species richness included the damselfishes (Pomacentridae), groupers and seabasses (Serranidae), wrasses (Labridae), and parrotfishes (Scaridae). Between banks and year, the damselfishes (Pomacentridae) were represented by 10 species. Groupers and seabasses were represented by a maximum of 8 species at the EFGB in 2009, and a minimum of 4 species at the WFGB in 2009. Wrasses were represented on average by 6 species, except for a minimum of 5 species at the EFGB in 2010. The parrotfishes were represented by 5 species between years and banks (Table 10.4.8 and Table 10.4.9).

Table 10.4.7.

Relative Abundance by Family for the 2009 and 2010 Surveys at Both the EFGB and WFGB

Family	Relative Abundance
Pomacentridae	41.5
Labridae	20.1
Serranidae	13.7
Inermiidae	9.7
Atherinopsidae	3.5
Scaridae	2.2
Acanthuridae	1.9
Kyphosidae	1.9
Tetraodontidae	1.5
Carangidae	1.3
Chaetodontidae	0.6
Sphyraenidae	0.6
Balistidae	0.4
Blenniidae	0.3
Pomacanthidae	0.2
Ostraciidae	0.2
Lutjanidae	0.1
Gobiidae	0.1
Monacanthidae	0.1
Mullidae	0.1
Cirrhitidae	<0.1
Holocentridae	<0.1
Muraenidae	<0.1
Mobulidae	<0.1
Aulostomidae	<0.1
Diodontidae	<0.1
Echeneidae	<0.1
Apogonidae	<0.1
Dasyatidae	<0.1

Table 10.4.8.

Mean Fish Density (number of individuals per 100 m²), Richness (number of species per family), and Mean Biomass by Family at the EFGB and WFGB in 2009

Family	Density (fishes/100 m²)		Species Richness		Mean Biomass (g/m²)	
	EFGB	WFGB	EFGB	WFGB	EFGB	WFGB
Acanthuridae	3.30	3.70	3	3	4.11	5.78
Atherinopsidae	21.46	0.00	1	0	0.59	0.00
Apogonidae	0.00	0.02	0	1	0.00	0.00
Aulostomidae	0.00	0.05	0	1	0.00	0.01
Balistidae	0.38	0.99	2	2	2.36	6.92
Blenniidae	0.64	0.92	1	1	0.01	0.02
Carangidae	3.14	3.18	3	5	15.84	63.97
Chaetodontidae	0.66	0.99	3	3	0.37	0.52
Cirrhitidae	0.07	0.07	1	1	0.00	0.00
Dasyatidae	0.00	0.02	0	1	0.00	1.81
Diodontidae	0.00	0.02	0	1	0.00	0.06
Echeneidae	0.05	0.00	1	0	0.03	0.00
Gobiidae	0.07	0.07	1	2	0.00	0.00
Holocentridae	0.00	0.09	0	1	0.00	0.16
Inermiidae	59.19	0.28	1	1	1.85	0.00
Kyphosidae	8.35	0.42	1	1	71.08	2.88
Labridae	59.63	29.76	6	6	7.46	10.78
Lutjanidae	0.19	0.26	1	1	1.27	0.94
Monacanthidae	0.14	0.14	1	2	0.08	0.34
Mullidae	0.05	0.21	1	1	0.05	0.45
Muraenidae	0.02	0.05	1	2	1.12	1.12
Ostraciidae	0.17	0.38	3	3	0.18	0.80
Pomacanthidae	0.71	0.40	3	3	2.73	1.86
Pomacentridae	91.11	72.01	10	10	5.60	4.07
Scaridae	3.23	2.83	5	5	6.38	10.01
Serranidae	22.57	13.91	8	4	38.51	18.80
Sphyraenidae	0.14	0.42	1	1	1.79	3.56
Tetraodontidae	2.50	2.95	1	1	0.08	0.09

Table 10.4.9.

Mean Fish Density (number of individuals per 100 m²), Richness (number of species per family), and Mean Biomass by Family at the EFGB and WFGB in 2010

Family	Density (fishes/100 m²)		Species Richness		Mean Biomass (g/m²)	
	EFGB	WFGB	EFGB	WFGB	EFGB	WFGB
Acanthuridae	2.49	1.78	3	3	3.55	3.59
Atherinopsidae	0.00	0.00	0	0	0.00	0.00
Apogonidae	0.00	0.00	0	0	0.00	0.00
Aulostomidae	0.00	0.00	0	0	0.00	0.00
Balistidae	0.61	0.65	3	1	3.96	3.78
Blenniidae	0.00	0.09	0	1	0.00	0.00
Carangidae	0.48	0.78	2	2	2.31	3.70
Chaetodontidae	0.77	1.13	3	4	0.23	0.38
Cirrhitidae	0.02	0.07	1	1	0.00	0.00
Dasyatidae	0.00	0.00	0	0	0.00	0.00
Diodontidae	0.00	0.02	0	1	0.00	0.05
Echeneidae	0.00	0.00	0	0	0.00	0.00
Gobiidae	0.25	0.04	1	1	0.01	0.00
Holocentridae	0.02	0.07	1	1	0.05	0.06
Inermiidae	0.00	0.00	0	0	0.00	0.00
Kyphosidae	1.45	1.07	1	1	10.07	3.72
Labridae	14.56	16.69	5	6	1.92	1.51
Lutjanidae	0.11	0.22	1	2	0.48	3.21
Monacanthidae	0.05	0.00	2	0	0.24	0.00
Mullidae	0.07	0.00	1	0	0.08	0.00
Muraenidae	0.00	0.02	0	1	0.00	0.02
Ostraciidae	0.25	0.11	2	1	0.32	0.03
Pomacanthidae	0.27	0.09	2	3	2.13	0.71
Pomacentridae	41.29	43.27	10	10	2.79	2.31
Scaridae	3.92	2.83	5	5	13.19	7.98
Serranidae	17.97	26.42	7	5	25.38	38.34
Sphyraenidae	1.06	1.63	1	1	6.14	17.68
Tetraodontidae	1.79	1.98	1	1	0.16	0.07

10.4.3. Diveristy and Evenness of Populations

Diversity and evenness was measured between banks and years by calculating Shannon-Wiener diversity indices (See Table 10.4.10). Diversity varied between banks and years, with the greatest diversity occurring at the WFGB in 2009. The lowest diversity was calculated for the WFGB in 2010. Evenness between banks and years remained relatively stable, with the least variation in communities occurring at the WFGB in 2009.

Table 10.4.10.

Shannon-Wiener Diversity Indices for the EFGB and WFGB in 2009 and 2010

Index	2009		2010	
	EFGB	WFGB	EFGB	WFGB
Samples (n)	24	24	25	26
Diversity (H')	1.05	1.12	1.01	0.99
Diversity (H'max)	1.78	1.80	1.72	1.71
Evenness (J')	0.59	0.62	0.59	0.58

When compared between banks, the WFGB had a significantly higher difference in diversity and evenness than was observed at the EFGB in 2009 (α=0.005, P-value=0.0028 and 0.0367 respectively). No significant difference in diversity or evenness was observed between the EFGB and WFGB in 2010. When diversity and evenness was compared between years at each bank, no significant difference was observed between years except for diversity at the WFGB between 2009 and 2010 (α=0.005, P-value=0.0050), suggesting a significantly greater species diversity at the WFGB in 2009 than 2010.

10.4.4. Trophic Group Comparisons

Species were grouped by trophic guild into four major categories: Herbivores, Piscivores, Invertivores, and Planktivores. As defined by NOAA’s Center for Coastal Monitoring and Assessment (CCMA) BioGeography Branch fish-trophic level database, the herbivore guild is comprised of Acanthuridae, Blennidae, Kyphosidae, Scaridae, and members of the Balistidae (Black Durgon), Gobiidae (Goldspot Goby), Pomacanthidae (Queen Angelfish), and Pomacentridae (Cocoa, Bi-Color, Yellowtail, and Dusky Damselfish) families. The piscivore guild is comprised of Aulostomidae, Carangidae, Inermiidae, Muraenidae, Sphyraenidae, and members of the Lutjanidae (Dog Snapper), and Serranidae (Yellowmouth, Tiger, Black, and Yellowfin Groupers, Graysby, and Scamp) families. The invertivore guild is comprised of Apogonidae, Chaetodontidae, Cirrhitidae, Dasyatidae, Diodontidae, Holocentridae, Monacanthidae, Mullidae, Muraenidae, Ostraciidae, Tetraodontidae, and members of the Balistidae (Ocean and Queen Triggerfish), Gobiidae (Neon Goby), Labridae (Spanish and Spotfin Hogfish, Clown, Yellowhead, Slippery Dick, and Bluehead Wrasse, and Puddingwife), Lutjanidae (Grey Snapper), and Pomacanthidae (Rock Beauty and French Angelfish), Pomacentridae (Brown Chromis, Sergeant Major, and Three-Spot Damselfish), Serranidae (Rock and

Red Hinds, and Coney) families. The planktivore guild is comprised of Echeneidae, and members of the Labridae (Creole Wrasse), Pomacentridae (Blue Chromis, Purple Reeffish, and Sunshinefish), and Serranidae (Creolefish) families. The mean density of herbivores ranged from 10 per 100 m^2 at the WFGB in 2010 to 47 per 100 m^2 at the EFGB in 2009. The mean density of piscivores ranged from 3 per 100 m^2 at the WFGB in 2010 to 63 per 100 m^2 at the EFGB in 2009. The invertivore trophic guild mean densities ranged from 2 per 100 m^2 at the EFGB in 2010 to 87 per 100 m^2 at the EFGB in 2009. The mean density of planktivores ranged from 25 per 100 m^2 at the EFGB in 2010 to 80 per 100 m^2 at the EFGB in 2009 (Table 10.4.11**)**. In both 2009 and 2010, the EFGB had a significantly higher difference in herbivore density than WFGB, P-value=0.0131 and 0.0244 respectively (α=0.005). The EFGB was also observed to be significantly higher in the piscivore density than the WFGB in 2009 (α=0.005, P-value=0.006), and significantly higher in the planktivore density than the WFGB in 2009 (α=0.005, P-value=0.0494). In yearly comparisons, a significant difference was observed between the densities of all trophic guilds at the EFGB between 2009 and 2010. Herbivore, piscivore, invertivore, and planktivore densities were all significantly different between 2009 and 2010, P-values=0.0013, 0.0036, 0.0021, and <0.0001 respectively (α=0.005). However, the WFGB only showed a significant difference between the densities of herbivores (α=0.005, P-value=0.0003) and invertivores (α=0.005, P-value=0.0193) between 2009 and 2010.

Table 10.4.11.

Comparison of Mean Density (fish per 100 m²) and Species Richness per Diver Survey of Herbivores, Piscivores, Invertivores, and Planktivores in Diver Surveys between the EFGB and WFGB in 2009 and 2010

NS= Not significant

Category	**2009**				**2010**			
	EFGB	**WFGB**	**P-value**	**Significance**	**EFGB**	**WFGB**	**P-value**	**Significance**
Herbivore Density	47	16	**0.0131**	**S**	14	10	**0.0244**	**S**
Piscivore Density	63	4	**0.006**	**S**	46	3	0.0702	NS
Invertivore Density	87	70	0.4316	NS	2	47	0.9135	NS
Planktivore Density	80	43	**0.0494**	**S**	25	38	0.5237	NS
Herbivore Richness	16	16	0.1167	NS	14	15	**0.0138**	**S**
Piscivore Richness	13	12	0.246	NS	7	9	0.0955	NS
Invertivore Richness	25	30	**<.0001**	**S**	25	22	0.7303	NS
Planktivore Richness	6	5	0.2286	NS	5	7	0.6425	NS

Species richness was recorded per trophic guild by year and bank. Herbivore richness ranged from 14 species at the EFGB in 2010 to 16 species at both the EFGB and WFGB in 2009. Piscivore richness ranged from 7 species at the EFGB in 2010 to 13 species at the EFGB in 2009. Invertivore richness was recorded at a minimum of 22 species at the WFGB in 2010 and a maximum of 25 species at the EFGB in 2009. Planktivore richness ranged from a low of 5 species at the WFGB in 2009 and EFGB in 2010, to a high of 7 species at the WFGB in 2010. A statistically significant difference was observed between the herbivore richness at the EFGB and WFGB in 2010 (α=0.005, P-value=0.0138) and between the invertivore richness at the EFGB and WFGB in 2009 (α=0.005, P-value<0.0001) (Table 10.4.11).

Species were grouped into trophic guild, and densities were compared between banks for each year (Table 10.4.12). The herbivore guild in 2009 showed significant differences in the density of Chub (*Kyphosus incisor*/*Kyphosus sectatrix*, α=0.005, P-value=0.0044), Redband Parrotfish (*Sparisoma aurofrenatum*, α=0.005, P-value=0.0169), Stoplight Parrotfish (*Sparisoma viride*, α=0.005, P-value=0.0076), and Black Durgon (*Melichthys niger*, α=0.005, P-value=0.0081). In 2010, the herbivore guild showed significant differences in the density of Bi-Color Damselfish (*Stegastes partitus*, α=0.005, P-value=0.007), while all other species showed no significant difference. The piscivore guild in 2009 showed significant differences in the density of Dog Snapper (*Lutjanus jocu*, α=0.005, P-value=0.0262), Tiger Grouper (*Mycteroperca tigris*, α=0.005, P-value=0.0428), Great Barracuda (*Sphyraena barracuda*, α=0.005, P-value=0.0021), and Bonnetmouth (*Emmelichthyops atlanticus*, α=0.005, P-value=0.0044). In 2010, no significant difference was observed in the densities of any piscivore species. The invertivore guild in 2009 showed significant differences in the densities of Spanish Hogfish (*Bodianus rufus*, α=0.005, P-value=0.0162) and Longspine Squirrelfish (*Holocentrus rufu*, α=0.005, P-value=0.0428). In 2010, this guild showed only a significant difference in the density of Spotfin Butterflyfish (*Chaetodon ocellatus*, α=0.005, P-value=0.0363). The planktivore guild showed significant differences in the densities of Creole Wrasse (*Clepticus parrae*, α=0.005, P-value=0.0424) and Purple Reeffish *(Chromis scotti*, α=0.005, P-value=0.0342). In 2010, the planktivore guild showed significant differences in the densities of Blue Chromis (*Chromis cyanea*, α=0.005, P-value=0.0416) and Purple Reeffish (*Chromis scotti*, α=0.005, P-value=0.0047).

Table 10.4.12.

Density Comparison between Banks for Herbivorous, Piscivorous, Invertivorous, and Planktivorous Fishes

Significant differences show P-values in bold. NS = Not significant.

Trophic Guild	**Species**	**2009**			**2010**		
		Number/100 m²			**Number/100 m²**		
		EFGB	**WFGB**	**P-value**	**EFGB**	**WFGB**	**P-value**
Herbivores	All Herbivores	47	16		13.5	10.3	
	Pomacentridae: *Stegastes variabilis* (Damselfish, Cocoa)	0.7	0.9	NS	1.6	1.8	NS
	Kyphosidae: *Kyphosus incisor / Kyphosus sectatrix* (Chub)	8.3	0.4	**0.0044**	1.4	1.1	NS
	Scaridae: *Scarus vetula* (Parrotfish, Queen)	1.3	1.3	NS	1.6	1.5	NS
	Pomacentridae: *Stegastes partitus* (Damselfish, Bi-color)	8.6	5.5	NS	3.0	1.8	**0.007**
	Acanthuridae: *Acanthurus coeruleus* (Tang, Blue)	2.8	3.3	NS	1.9	1.4	NS
	Atherinopsidae: *Menidiinae* sp. (Silversides)	21.5	0.0	NS	0.0	0.0	NS
	Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	0.3	0.3	NS	0.1	0.1	NS
	Pomacanthidae: *Holacanthus ciliaris* (Angelfish, Queen)	0.1	0.1	NS	0.0	0.0	NS
	Blenniidae: *Ophioblennius macclurei* (Blenny, Redlip)	0.6	0.9	NS	0.0	0.1	NS
	Scaridae: *Sparisoma aurofrenatum* (Parrotfish, Redband)	1.2	0.2	**0.0169**	0.6	0.3	NS
	Pomacentridae: *Microspathodon chrysurus* (Damselfish, Yellowtail)	0.4	0.8	NS	0.4	0.2	NS
	Scaridae: *Sparisoma viride* (Parrotfish, Stoplight)	0.5	1.2	**0.0076**	0.9	0.7	NS
	Acanthuridae: *Acanthurus bahianus* (Surgeonfish, Ocean)	0.2	0.1	NS	0.5	0.3	NS
	Balistidae: *Melichthys niger* (Durgon, Black)	0.3	0.9	**0.0081**	0.5	0.7	NS
	Scaridae: *Scarus taeniopterus* (Parrotfish, Princess)	0.1	0.0	NS	0.8	0.4	NS
	Pomacentridae: *Stegastes adustus* (Damselfish, Dusky)	0.1	0.4	NS	0.2	0.1	NS

Trophic Guild	Species	2009			2010		
		Number/100 m²			Number/100 m²		
		EFGB	WFGB	P-value	EFGB	WFGB	P-value
	Scaridae: *Sparisoma atomarium* (Parrotfish, Greenblotch)	0.0	0.0	NS	0.0	0.0	NS
	Gobiidae: *Gnatholepis thompsoni* (Goby, Goldspot)	0.0	0.0	NS	0.0	0.0	NS
	Scaridae: *Scarus iseri* (Parrotfish, Striped)	0.0	0.0	NS	0.1	0.0	NS
Piscivores	All Piscivores	63.4	4.4		46.3	3.4	
	Lutjanidae: *Lutjanus jocu* (Snapper, Dog)	0.2	0.0	**0.0262**	0.0	0.1	NS
	Serranidae: *Mycteroperca interstitialis* (Grouper, Yellowmouth)	0.3	0.1	NS	0.1	0.1	NS
	Serranidae: *Mycteroperca tigris* (Grouper, Tiger)	0.1	0.0	**0.0428**	0.2	0.2	NS
	Carangidae: *Caranx latus* (Jack, Horse-eye)	2.0	0.4	NS	0.0	0.1	NS
	Carangidae: *Caranx lugubris* (Jack, Black)	0.1	0.2	NS	0.1	0.0	NS
	Serranidae: *Cephalopholis cruentata* (Graysby)	0.3	0.4	NS	0.4	0.4	NS
	Sphyraenidae: *Sphyraena barracuda* (Barracuda, Great)	0.1	0.4	**0.0021**	1.1	1.6	NS
	Serranidae: *Mycteroperca bonaci* (Grouper, Black)	0.0	0.0	NS	0.0	0.0	NS
	Serranidae: *Mycteroperca phenax* (Scamp)	0.0	0.0	NS	0.0	0.0	NS
	Inermiidae: *Emmelichthyops atlanticus* (Bonnetmouth)	59.2	0.3	**0.0044**	0.0	0.0	NS
	Carangidae: *Carangoides ruber* (Jack, Bar)	1.0	0.1	NS	0.4	0.7	NS
	Carangidae: *Caranx crysos* (Blue runner)	0.1	0.0	NS	0.0	0.0	NS
	Muraenidae: *Gymnothorax meleagris* (Moray, Spotted)	0.0	0.0	NS	0.0	0.0	NS
	Aulostomidae: *Aulostomus maculatus* (Trumpetfish)	0.0	0.0	NS	0.0	0.0	NS
	Carangidae: *Elagatis bipinnulata* (Rainbow runner)	0.0	2.4	NS	0.0	0.0	NS
	Serranidae: *mycteroperca venenosa* (Grouper, Yellowfin)	0.0	0.0	NS	0.0	0.0	NS
Invertivores	All Invertivores	87.1	69.8		2.2	46.9	
	Pomacentridae: *Chromis multilineata* (Chromis,	59.7	42.8	NS	32.8	32.9	NS

Trophic Guild	Species	2009			2010		
		Number/100 m²			Number/100 m²		
		EFGB	WFGB	P-value	EFGB	WFGB	P-value
	Brown)						
	Labridae: *Thalassoma lucasanum* (Wrasse, Bluehead)	17.6	13.3	NS	6.4	6.2	NS
	Pomacentridae: *Stegastes planifrons* (Damselfish, Three-spot)	3.3	3.7	NS	1.6	1.2	NS
	Cirrhitidae: *Amblycirrhitus pinos* (Hawkfish, Redspotted)	0.1	0.1	NS	0.0	0.1	NS
	Tetraodontidae: Canthigaster *rostrata* (Puffer, Sharpnose)	2.5	2.9	NS	1.8	2.0	NS
	Labridae: *Bodianus rufus* (Hogfish, Spanish)	1.1	2.0	**0.0162**	1.4	2.0	NS
	Chaetodontidae: *Chaetodon ocellatus* (Butterflyfish, Spotfin)	0.2	0.2	NS	0.0	0.2	**0.0265**
	Pomacanthidae: *Holacanthus tricolor* (Angelfish, Rock Beauty)	0.4	0.3	NS	0.1	0.0	NS
	Chaetodontidae: *Chaetodon sedentarius* (Butterflyfish, Reef)	0.4	0.5	NS	0.7	0.8	NS
	Monacanthidae: *Cantherhines pullus* (Filefish, Orange Spotted)	0.1	0.1	NS	0.0	0.0	NS
	Balistidae: *Canthidermis sufflamen* (Triggerfish, Ocean)	0.1	0.1	NS	0.0	0.0	NS
	Ostraciidae: *Lactophrys triqueter* (Trunkfish, Smooth)	0.1	0.2	NS	0.2	0.1	NS
	Labridae: *Halichoeres maculipinna* (Wrasse, Clown)	0.3	1.2	NS	0.0	0.1	NS
	Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	0.2	0.6	NS	0.1	0.3	NS
	Gobiidae: *Elacatinus oceanops* (Goby, Neon)	0.1	0.0	NS	0.2	0.0	NS
	Pomacanthidae: *Pomacanthus paru* (Angelfish, French)	0.2	0.0	NS	0.2	0.0	NS
	Serranidae: *Epinephelus adscensionis* (Hind, Rock)	0.0	0.0	NS	0.0	0.0	NS
	Serranidae: *Epinephelus guttatus* (Hind, Red)	0.0	0.0	NS	0.0	0.0	NS
	Labridae: *Halichoeres garnoti* (Wrasse, Yellowhead)	0.2	0.4	NS	0.1	0.4	NS

Trophic Guild	**Species**	**2009**			**2010**		
		Number/100 m²			**Number/100 m²**		
		EFGB	**WFGB**	**P-value**	**EFGB**	**WFGB**	**P-value**
	Mullidae: *Pseudupeneus maculatus* (Goatfish, Spotted)	0.0	0.0	NS	0.0	0.0	NS
	Ostraciidae: *Acanthostracion polygonius* (Cowfish, Honeycomb)	0.0	0.1	NS	0.0	0.0	NS
	Chaetodontidae: *Prognathodes aculeatus* (Butterflyfish, Longsnout)	0.0	0.3	NS	0.1	0.2	NS
	Labridae: *Bodianus pulchellus* (Hogfish, Spotfin)	0.0	0.0	NS	0.0	0.0	NS
	Ostraciidae: *Lactophrys bicaudalis* (Trunkfish, Spotted)	0.0	0.1	NS	0.0	0.0	NS
	Lutjanidae: *Lutjanus agennes* (Snapper, Grey)	0.0	0.3	NS	0.1	0.1	NS
	Apogonidae: *Apogon* sp. (Cardinal fish sp.)	0.0	0.0	NS	0.0	0.0	NS
	Holocentridae: *Holocentrus rufus* (Squirrelfish, Longspine)	0.0	0.1	**0.0428**	0.0	0.1	NS
	Diodontidae: *Diodon holocanthus* (Ballonfish)	0.0	0.0	NS	0.0	0.0	NS
	Monacanthidae: *Cantherhines macrocerus* (Filefish, Whitespotted)	0.0	0.0	NS	0.0	0.0	NS
	Mullidae: *Mulloidichthys martinicus* (Goatfish, Yellow)	0.0	0.2	NS	0.1	0.0	NS
	Muraenidae: *Gymnothorax miliaris* (Moray, Goldentail)	0.0	0.0	NS	0.0	0.0	NS
	Dasyatidae: *Dasyatis americana* (Stingray, Southern)	0.0	0.0	NS	0.0	0.0	NS
	Labridae: *Halichoeres radiatus* (Pudding wife)	0.0	0.0	NS	0.0	0.0	NS
	Labridae: *Halichoeres bivittatus* (Wrasse, Slippery Dick)	0.0	0.0	NS	0.0	0.2	NS
	Tetraodontidae: *Sphoeroides spengleri* (Puffer, Bandtail)	0.0	0.0	NS	0.0	0.0	NS
	Chaetodontidae: *Chaetodon striatus* (Butterflyfish, Banded)	0.0	0.0	NS	0.0	0.0	NS
	Balistidae: *Balistes vetula* (Triggerfish, Queen)	0.0	0.0	NS	0.0	0.0	NS

Trophic Guild	Species	2009			2010		
		Number/100 m^2			Number/100 m^2		
		EFGB	WFGB	P-value	EFGB	WFGB	P-value
	Serranidae: *Liopropoma rubre* (Bass, Peppermint)	0.0	0.0	NS	0.0	0.0	NS
	Holocentridae: *holocentrus adscensionis* (Squirrelfish)	0.0	0.0	NS	0.0	0.0	NS
	Serranidae: *Cephalopholis fulva* (Grouper, Coney)	0.0	0.0	NS	0.0	0.0	NS
Planktivores	All Planktivores	80.2	43.5		25.0	38.5	
	Serranidae: *Paranthias furcifer* (Creolefish)	21.8	13.4	NS	17.2	25.6	NS
	Pomacentridae: *Chromis cyanea* (Chromis, Blue)	12.4	10.6	NS	0.9	2.9	**0.0416**
	Labridae: *Clepticus parrae* (Wrasse, Creole)	40.3	12.8	**0.0424**	6.6	7.9	NS
	Pomacentridae: *Chromis scotti* (Reeffish, Purple)	3.3	5.7	**0.0342**	0.5	1.8	**0.0047**
	Pomacentridae: *Chromis insolata* (Sunshinefish)	2.5	1.0	NS	0.2	0.3	NS
	Echeneidae: *Echeneidae* sp. (Remora)	0.0	0.0	NS	0.0	0.0	NS
	Lutjanidae: *Lutjanus argentiventris* (Snapper, Yellowtail)	0.0	0.0	NS	0.0	0.0	NS

When species densities were compared at each bank between years (Table 10.4.13), a significant difference was observed between 16 species at the EFGB between 2009 and 2010. This included the herbivorious Cocoa Damselfish (*Stegastes variabilis*, α=0.005, P-value=0.0425), Bi-Color Damselfish (*Stegastes partitus*, α=0.005, P-value<0.0001), Redlip Blenny (*Ophioblennius macclurei*, α=0.005, P-value=0.0025), and Princess Parrotfish (*Scarus taeniopterus*, α=0.005, P-value=0.0097), the piscivorous Dog Snapper (*Lutjanus jocu*, α=0.005, P-value=0.0262), Horse-Eye Jack (*Caranx latus*, α=0.005, P-value=0.015), Great Barracuda (*Sphyraena barracuda*, α=0.005, P-value=0.0002), and Bonnetmouth (*Emmelichthyops atlanticus*, α=0.005, P-value=0.0027), the invertivorous Bluehead Wrasse (*Thalassoma lucasanum*, α=0.005, P-value=0.0015), Spotfin Butterflyfish (*Chaetodon ocellatus*, α=0.005, P-value=0.0242), Rock Beauty (*Holacanthus tricolor*, α=0.005, P-value=0.0305), and Clown Wrasse (*Halichoeres maculipinna*, α=0.005, P-value=0.0241), and the planktivorous Blue Chromis (*Chromis cyanea*, α=0.005, P-value<0.0001), Creole Wrasse (*Clepticus parrae*, α=0.005, P-value=0.0002), Purple Reeffish (*Chromis scotti*, α=0.005, P-value=0.0238), and Sunshinefish (*Chromis insolata*, α=0.005, P-value=0.008).

At the WFGB, a significant difference in density was observed between 18 species between 2009 and 2010. This included the herbivorous Bi-Color Damselfish (*Stegastes partitus*, α=0.005, P-value<0.0001), Redlip Blenny (*Ophioblennius macclurei*, α=0.005, P-value=0.001), Yellowtail Damselfish (*Microspathodon chrysurus*, α=0.005, P-value=0.0009), Stoplight Parrotfish (*Sparisoma viride*, α=0.005, P-value=0.0161), and

Princess Parrotfish (*Scarus taeniopterus*, α=0.005, P-value=0.0256), the piscivorous Tiger Grouper (*Mycteroperca tigris*, α=0.005, P-value=0.0051), Black Jack (*Caranx lugubris*, α=0.005, P-value=0.0094), and Great Barracuda (*Sphyraena barracuda*, α=0.005, P-value<0.0001), the invertivorous Bluehead Wrasse (*Thalassoma lucasanum*, α=0.005, P-value=0.0044), Three-Spot Damselfish (*Stegastes planifrons*, α=0.005, P-value=0.0004), Rock Beauty (*Holacanthus tricolor*, α=0.005, P-value=0.0047), Orange-Spotted Filefish (*Cantherhines pullus*, α=0.005, P-value=0.0482), Clown Wrasse (*Clepticus parrae*, α=0.005, P-value=0.0102), and Honeycomb Cowfish (*Acanthostracion polygonius*, α=0.005, P-value=0.0482), and the planktivorous Blue Chromis (*Chromis cyanea*, α=0.005, P-value=0.0023), Creole Wrasse (*Clepticus parrae*, α=0.005, P-value=0.0008), Purple Reeffish (*Chromis scotti*, α=0.005, P-value=0.007), and Sunshinefish (*Chromis insolata*, α=0.005, P-value=0.0141) (Table 10.4.13)

Table 10.4.13.

Abundances between Years for Herbivores, Piscivores, Invertivores, and Planktivores

Comparisons of groups where student's t-tests were performed are in bold with appropriate P-values where significant. NS = Not significant

Trophic Guild	**Species**	**EFGB**			**WFGB**		
		Number/100 m^2			**Number/100 m^2**		
		2009	**2010**	**P-value**	**2009**	**2010**	**P-value**
Herbivores	All Herbivores	47	13.5		16	10.3	
	Pomacentridae: *Stegastes variabilis* (Damselfish, Cocoa)	0.7	1.6	**0.0425**	0.9	1.8	NS
	Kyphosidae: *Kyphosus incisor / Kyphosus sectatrix* (Chub)	8.3	1.4	NS	0.4	1.1	NS
	Scaridae: *Scarus vetula* (Parrotfish, Queen)	1.3	1.6	NS	1.3	1.5	NS
	Pomacentridae: *Stegastes partitus* (Damselfish, Bi-color)	8.6	3.0	**<0.0001**	5.5	1.8	**<0.0001**
	Acanthuridae: *Acanthurus coeruleus* (Tang, Blue)	2.8	1.9	NS	3.3	1.4	NS
	Atherinopsidae: *Menidiina*e sp. (Silversides)	21.5	0.0	NS	0.0	0.0	NS
	Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	0.3	0.1	NS	0.3	0.1	NS
	Pomacanthidae: *Holacanthus ciliaris* (Angelfish, Queen)	0.1	0.0	NS	0.1	0.0	NS
	Blenniidae: *Ophioblennius macclurei* (Blenny, Redlip)	0.6	0.0	**0.0025**	0.9	0.1	**0.001**
	Scaridae: *Sparisoma aurofrenatum* (Parrotfish, Redband)	1.2	0.6	NS	0.2	0.3	NS
	Pomacentridae:	0.4	0.4	NS	0.8	0.2	**0.0009**

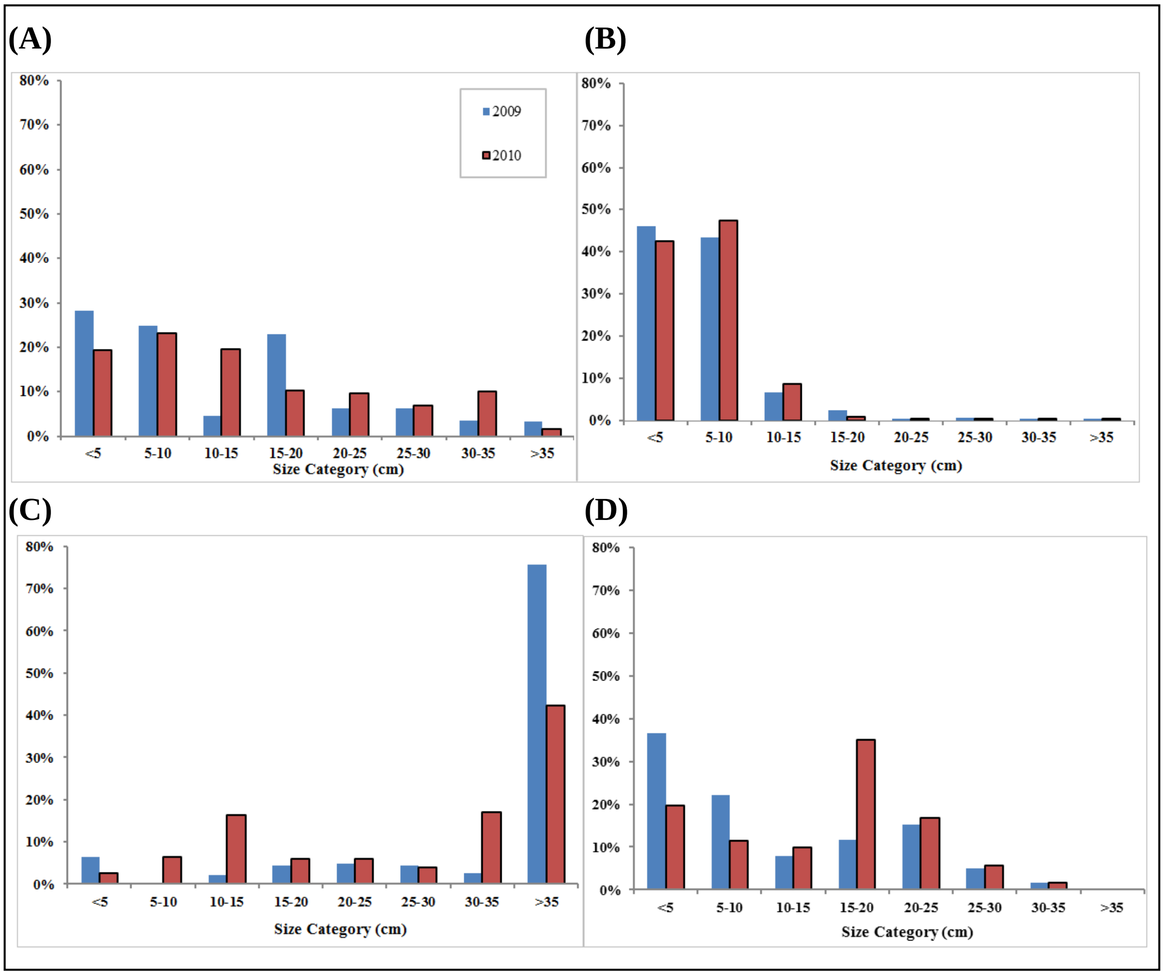
Trophic Guild	**Species**	**EFGB**			**WFGB**		
		Number/100 m^2			**Number/100 m^2**		
		2009	**2010**	**P-value**	**2009**	**2010**	**P-value**
	Microspathodon chrysurus (Damselfish, Yellowtail)						
	Scaridae: *Sparisoma viride* (Parrotfish, Stoplight)	0.5	0.9	NS	1.2	0.7	**0.0161**
	Acanthuridae: *Acanthurus bahianus* (Surgeonfish, Ocean)	0.2	0.5	NS	0.1	0.3	NS
	Balistidae: *Melichthys niger* (Durgon, Black)	0.3	0.5	NS	0.9	0.7	NS
	Scaridae: *Scarus taeniopterus* (Parrotfish, Princess)	0.1	0.8	**0.0097**	0.0	0.4	**0.0256**
	Pomacentridae: *Stegastes adustus* (Damselfish, Dusky)	0.1	0.2	NS	0.4	0.1	NS
	Scaridae: *Sparisoma atomarium* (Parrotfish, Greenblotch)	0.0	0.0	NS	0.0	0.0	NS
	Gobiidae: *Gnatholepis thompsoni* (Goby, Goldspot)	0.0	0.0	NS	0.0	0.0	NS
	Scaridae: *Scarus iseri* (Parrotfish, Striped)	0.0	0.1	NS	0.0	0.0	NS
Piscivores	All Piscivores	63.4	46.3		4.4	3.4	
	Lutjanidae: *Lutjanus jocu* (Snapper, Dog)	0.2	0.0	**0.0262**	0.0	0.1	NS
	Serranidae: *Mycteroperca interstitialis* (Grouper, Yellowmouth)	0.3	0.1	NS	0.1	0.1	NS
	Serranidae: *Mycteroperca tigris* (Grouper, Tiger)	0.1	0.2	NS	0.0	0.2	**0.0051**
	Carangidae: *Caranx latus* (Jack, Horse-eye)	2.0	0.0	**0.015**	0.4	0.1	NS
	Carangidae: *Caranx lugubris* (Jack, Black)	0.1	0.1	NS	0.2	0.0	**0.0094**
	Serranidae: *Cephalopholis cruentata* (Graysby)	0.3	0.4	NS	0.4	0.4	NS
	Sphyraenidae: *Sphyraena barracuda* (Barracuda, Great)	0.1	1.1	**0.0002**	0.4	1.6	**<0.0001**
	Serranidae: *Mycteroperca bonaci* (Grouper, Black)	0.0	0.0	NS	0.0	0.0	NS
	Serranidae: *Mycteroperca phenax* (Scamp)	0.0	0.0	NS	0.0	0.0	NS
	Inermiidae: *Emmelichthyops atlanticus* (Bonnetmouth)	59.2	0.0	**0.0027**	0.3	0.0	NS
	Carangidae: *Carangoides ruber* (Jack, Bar)	1.0	0.4	NS	0.1	0.7	NS
	Carangidae: *Caranx crysos* (Blue runner)	0.1	0.0	NS	0.0	0.0	NS

Trophic Guild	**Species**	**EFGB**			**WFGB**		
		Number/100 m^2			**Number/100 m^2**		
		2009	**2010**	**P-value**	**2009**	**2010**	**P-value**
	Muraenidae: *Gymnothorax meleagris* (Moray, Spotted)	0.0	0.0	NS	0.0	0.0	NS
	Aulostomidae: *Aulostomus maculatus* (Trumpetfish)	0.0	0.0	NS	0.0	0.0	NS
	Carangidae: *Elagatis bipinnulata* (Rainbow runner)	0.0	0.0	NS	2.4	0.0	NS
	Serranidae: *mycteroperca venenosa* (Grouper, Yellowfin)	0.0	0.0	NS	0.0	0.0	NS
Invertivores	All Invertivores	87.1	2.2		69.8	46.9	
	Pomacentridae: *Chromis multilineata* (Chromis, Brown)	59.7	32.8	NS	42.8	32.9	NS
	Labridae: *Thalassoma lucasanum* (Wrasse, Bluehead)	17.6	6.4	**0.0015**	13.3	6.2	**0.0044**
	Pomacentridae: *Stegastes planifrons* (Damselfish, Three-spot)	3.3	1.6	NS	3.7	1.2	**0.0004**
	Cirrhitidae: *Amblycirrhitus pinos* (Hawkfish, Redspotted)	0.1	0.0	NS	0.1	0.1	NS
	Tetraodontidae: Canthigaster *rostrata* (Puffer, Sharpnose)	2.5	1.8	NS	2.9	2.0	NS
	Labridae: *Bodianus rufus* (Hogfish, Spanish)	1.1	1.4	NS	2.0	2.0	NS
	Chaetodontidae: *Chaetodon ocellatus* (Butterflyfish, Spotfin)	0.2	0.0	**0.0242**	0.2	0.2	NS
	Pomacanthidae: *Holacanthus tricolor* (Angelfish, Rock Beauty)	0.4	0.1	**0.0305**	0.3	0.0	**0.0047**
	Chaetodontidae: *Chaetodon sedentarius* (Butterflyfish, Reef)	0.4	0.7	NS	0.5	0.8	NS
	Monacanthidae: *Cantherhines pullus* (Filefish, Orange Spotted)	0.1	0.0	NS	0.1	0.0	**0.0428**
	Balistidae: *Canthidermis sufflamen* (Triggerfish, Ocean)	0.1	0.0	NS	0.1	0.0	NS
	Ostraciidae: *Lactophrys triqueter* (Trunkfish, Smooth)	0.1	0.2	NS	0.2	0.1	NS
	Labridae: *Halichoeres maculipinna* (Wrasse, Clown)	0.3	0.0	**0.0241**	1.2	0.1	**0.0102**

Trophic Guild	Species	EFGB			WFGB		
		Number/100 m²			Number/100 m²		
		2009	2010	P-value	2009	2010	P-value
	Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	0.2	0.1	NS	0.6	0.3	NS
	Gobiidae: *Elacatinus oceanops* (Goby, Neon)	0.1	0.2	NS	0.0	0.0	NS
	Pomacanthidae: *Pomacanthus paru* (Angelfish, French)	0.2	0.2	NS	0.0	0.0	NS
	Serranidae: *Epinephelus adscensionis* (Hind, Rock)	0.0	0.0	NS	0.0	0.0	NS
	Serranidae: *Epinephelus guttatus* (Hind, Red)	0.0	0.0	NS	0.0	0.0	NS
	Labridae: *Halichoeres garnoti* (Wrasse, Yellowhead)	0.2	0.1	NS	0.4	0.4	NS
	Mullidae: *Pseudupeneus maculatus* (Goatfish, Spotted)	0.0	0.0	NS	0.0	0.0	NS
	Ostraciidae: *Acanthostracion polygonius* (Cowfish, Honeycomb)	0.0	0.0	NS	0.1	0.0	**0.0482**
	Chaetodontidae: *Prognathodes aculeatus* (Butterflyfish, Longsnout)	0.0	0.1	NS	0.3	0.2	NS
	Labridae: *Bodianus pulchellus* (Hogfish, Spotfin)	0.0	0.0	NS	0.0	0.0	NS
	Ostraciidae: *Lactophrys bicaudalis* (Trunkfish, Spotted)	0.0	0.0	NS	0.1	0.0	NS
	Lutjanidae: *Lutjanus agennes* (Snapper, Grey)	0.0	0.1	NS	0.3	0.1	NS
	Apogonidae: *Apogon* sp. (Cardinal fish sp.)	0.0	0.0	NS	0.0	0.0	NS
	Holocentridae: *Holocentrus rufus* (Squirrelfish, Longspine)	0.0	0.0	NS	0.1	0.1	NS
	Diodontidae: *Diodon holocanthus* (Ballonfish)	0.0	0.0	NS	0.0	0.0	NS
	Monacanthidae: *Cantherhines macrocerus* (Filefish, Whitespotted)	0.0	0.0	NS	0.0	0.0	NS
	Mullidae: *Mulloidichthys martinicus* (Goatfish, Yellow)	0.0	0.1	NS	0.2	0.0	NS
	Muraenidae: *Gymnothorax miliaris* (Moray, Goldentail)	0.0	0.0	NS	0.0	0.0	NS
	Dasyatidae: *Dasyatis americana* (Stingray, Southern)	0.0	0.0	NS	0.0	0.0	NS

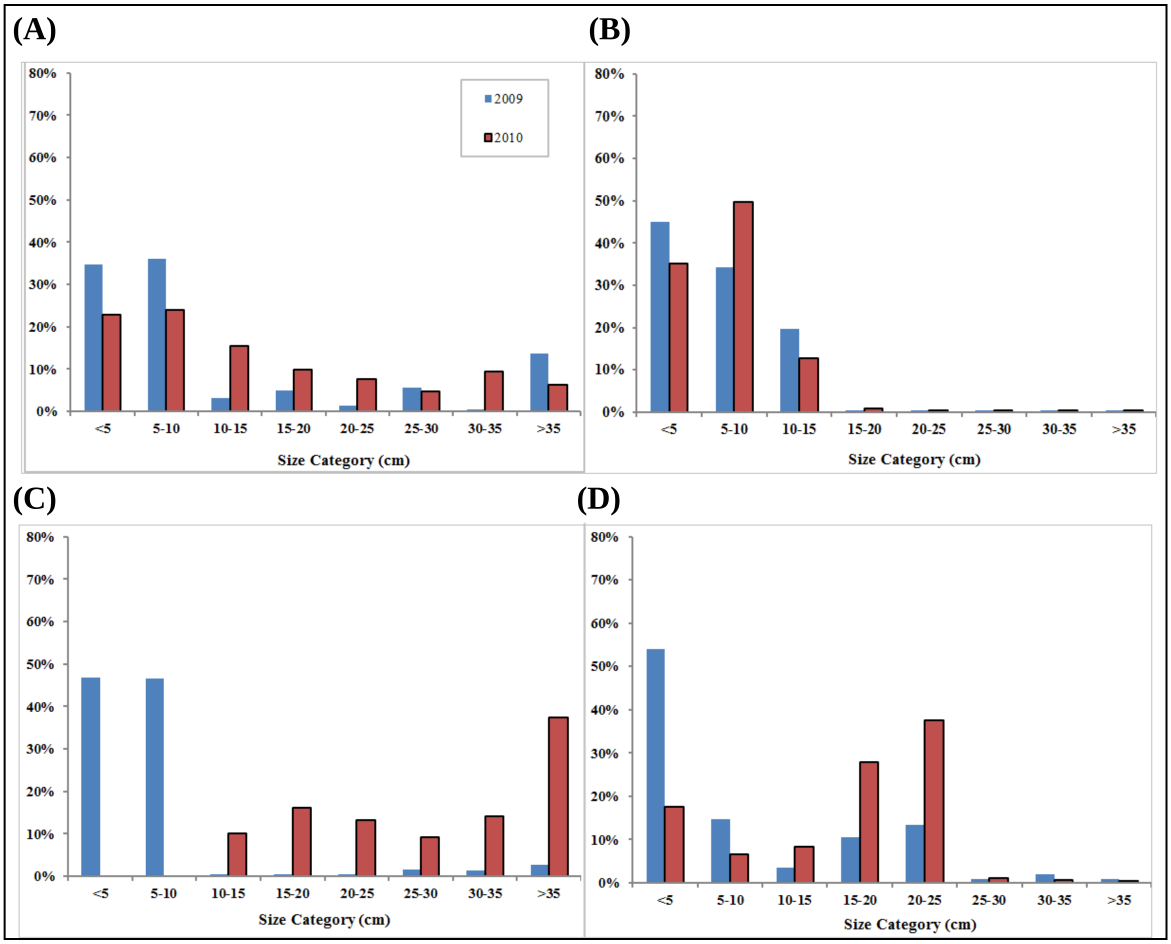
Trophic Guild	**Species**	**EFGB**			**WFGB**		
		Number/100 m^2			**Number/100 m^2**		
		2009	**2010**	**P-value**	**2009**	**2010**	**P-value**
	Labridae: *Halichoeres radiatus* (Pudding wife)	0.0	0.0	NS	0.0	0.0	NS
	Labridae: *Halichoeres bivittatus* (Wrasse, Slippery Dick)	0.0	0.0	NS	0.0	0.2	NS
	Tetraodontidae: *Sphoeroides spengleri* (Puffer, Bandtail)	0.0	0.0	NS	0.0	0.0	NS
	Chaetodontidae: *Chaetodon striatus* (Butterflyfish, Banded)	0.0	0.0	NS	0.0	0.0	NS
	Balistidae: *Balistes vetula* (Triggerfish, Queen)	0.0	0.0	NS	0.0	0.0	NS
	Serranidae: *Liopropoma rubre* (Bass, Peppermint)	0.0	0.0	NS	0.0	0.0	NS
	Holocentridae: *holocentrus adscensionis* (Squirrelfish)	0.0	0.0	NS	0.0	0.0	NS
	Serranidae: *Cephalopholis fulva* (Grouper, Coney)	0.0	0.0	NS	0.0	0.0	NS
Planktivores	All Planktivores	80.2	25.0		43.5	38.5	
	Serranidae: *Paranthias furcifer* (Creolefish)	21.8	17.2	NS	13.4	25.6	NS
	Pomacentridae: *Chromis cyanea* (Chromis, Blue)	12.4	0.9	**<0.0001**	10.6	2.9	**0.0023**
	Labridae: *Clepticus parrae* (Wrasse, Creole)	40.3	6.6	**0.0002**	12.8	7.9	**0.0008**
	Pomacentridae: *Chromis scotti* (Reeffish, Purple)	3.3	0.5	**0.0238**	5.7	1.8	**0.007**
	Pomacentridae: *Chromis insolata* (Sunshinefish)	2.5	0.2	**0.008**	1.0	0.3	**0.0141**
	Echeneidae: *Echeneidae* sp. (Remora)	0.0	0.0	NS	0.0	0.0	NS
	Lutjanidae: *Lutjanus argentiventris* (Snapper, Yellowtail)	0.0	0.0	NS	0.0	0.0	NS

Size-frequency distributions were graphed for each trophic guild by bank. Herbivores, invertivores, and planktivores were dominated by smaller individuals, whereas piscivores were substantially larger individuals (See Figure 10.4.1 and Figure 10.4.2).



Blue columns are 2009 data; red columns are 2010 data.

Figure 10.4.1. WFGB size distribution by trophic guild. (A) herbivores, (B) invertivores, (C) piscivores, and (D) planktivores.



Blue columns are 2009 data; red columns are 2010 data.

Figure 10.4.2. EFGB size distribution by trophic guild. (A) herbivores , (B) invertivores, (C) piscivores, and (D) planktivores.

10.4.5. Biomass Analysis

Mean biomass for the 2009 and 2010 surveys was calculated to be 113.28 g per 1 m^2 (±195.68 SD). The mean biomass ranged from 73 g/m^2 (EFGB in 2010) to 162.52 g/m^2 (EFGB in 2009) (Table 10.4.14). No significant difference was observed in biomass between bank or year when evaluated with a Student's t-test.

Table 10.4.14.

Visual fish Survey Sampling Biomass Statistics for the EFGB and WFGB in 2009 and 2010

Category	**2009**		**2010**	
	EFGB	**WFGB**	**EFGB**	**WFGB**
Total Biomass in All Surveys (g/m^2)	689199	572273	322479	400455
Mean Biomass (g/m^2)	162.52	134.94	73.00	87.17

When grouped by family, chubs (Kyphosidae) contributed the most biomass to the EFGB surveys in 2009 comprising 44.2% of the total biomass. This was primarily due to a large school of 200 chub recorded during one survey. Similar to the exclusion of rare manta ray sightings, it is reasonable to exclude other rare occurrences that strongly skew results. When this record was removed, chub fell to 21.2% of the total biomass, and the family contributing most to the 2009 EFGB surveys was the groupers and seabass (Serranidae) at 33.6%. At the WFGB in 2009, the jack family (Carangidae) contributed 47.3% of the biomass. This again was dominantly due to one large school (100 rainbow runner) recorded during one survey. When this record was removed, the jack family (Carangidae) biomass contribution fell to 5.9%, and the grouper and seabass family (Serranidae) became the dominant contributor, with 24.9% of biomass. The data from both the EFGB and WFGB in 2010 was comparatively free of anomalous data, and the groupers and seabass (Serranidae) contributed most to biomass, at 34.8% (EFGB) and 44.0% (WFGB) (Table 10.4.15).

Table 10.4.15.

Total Biomass (g/m^2) for Each Family

In parentheses are the percent contributions of each family to the total biomass of the bank per year. *The EFGB 2009 data shows biomass with the removal of one record of a large school of chub (Kyphosidae). **WFGB 2009 data shows biomass with the removal of one record of a large school of rainbow runners from the jack family (Carangidae).

Family	**Total Biomass (g/m^2)**			
	2009		**2010**	
	EFGB*	**WFGB****	**EFGB**	**WFGB**
Acanthuridae	98.64 (3.6)	138.68 (7.7)	88.82 (4.9)	93.36 (4.1)
Atherinopsidae	--	--	--	--
Apogonidae	14.28 (0.5)	0 (0)	--	--

Family	**Total Biomass (g/m²)**			
	2009		**2010**	
	EFGB*	**WFGB****	**EFGB**	**WFGB**
Aulostomidae	--	0.34 (0)	--	--
Balistidae	56.57 (2.1)	166.08 (9.2)	98.96 (5.4)	98.4 (4.3)
Blenniidae	0.23 (0)	0.47 (0)	--	0.07 (0)
Carangidae	380.16 (13.8)	106.02 (5.9)	57.79 (3.2)	96.09 (4.2)
Chaetodontidae	8.78 (0.3)	12.45 (0.7)	5.72 (0.3)	9.93 (0.4)
Cirrhitidae	0.02 (0)	0.03 (0)	0 (0)	0.04 (0)
Dasyatidae	--	43.47 (2.4)	--	--
Diodontidae	--	1.41 (0.1)	--	1.41 (0.1)
Echeneidae	0.84 (0)	--	--	--
Gobiidae	0 (0)	0 (0)	0.14 (0)	0 (0)
Holocentridae	--	3.76 (0.2)	1.16 (0.1)	1.55 (0.1)
Inermiidae	44.28 (1.6)	0.01 (0)	--	--
Kyphosidae	583.82 (21.2)	69.12 (3.8)	251.78 (13.8)	96.7 (4.3)
Labridae	179.14 (6.5)	258.75 (14.3)	48.11 (2.6)	39.26 (1.7)
Lutjanidae	30.45 (1.1)	22.65 (1.3)	12.12 (0.7)	83.58 (3.7)
Monacanthidae	1.84 (0.1)	8.2 (0.5)	5.9 (0.3)	--
Mullidae	1.23 (0)	10.72 (0.6)	1.88 (0.1)	--
Muraenidae	26.83 (1)	26.88 (1.5)	--	0.43 (0)
Ostraciidae	4.21 (0.2)	19.11 (1.1)	7.92 (0.4)	0.9 (0)
Pomacanthidae	65.63 (2.4)	44.69 (2.5)	53.3 (2.9)	18.44 (0.8)
Pomacentridae	134.44 (4.9)	97.68 (5.4)	69.66 (3.8)	60.17 (2.7)
Scaridae	153.22 (5.6)	240.35 (13.3)	329.7 (18.1)	207.45 (9.2)
Serranidae	924.2 (33.6)	451.17 (24.9)	634.53 (34.8)	996.86 (44.0)
Sphyraenidae	42.99 (1.6)	85.36 (4.7)	153.56 (8.4)	459.71 (20.3)
Tetraodontidae	1.95 (0.1)	2.11 (0.1)	3.94 (0.2)	1.94 (0.1)

Although biomass was dominated by the grouper and seabass family (Serranidae) at both banks in 2009 and 2010 (when observations of large schools or large rays are removed), a single species, Creolefish (*Paranthias furcifer*), contributes 92.06% ± 3.65 of the biomass for the family, ranging from 86.84% at the WFGB in 2010 to 95.18% at the EFGB in 2010.

Biomass was grouped by trophic guild for each year and bank. The contribution of each trophic guild to total biomass varied between year and bank, with herbivores comprising the greatest biomass at the EFGB in both 2009 and 2010 (Figure 10.4.3). A significantly higher difference was observed between the piscivores (α=0.005, P-value=0.0074) at the WFGB and a significantly higher difference was observed for the invertivores (α=0.005, P-value=0.0401) at the EFGB in 2010. No significant difference observed in trophic guilds between 2009 and 2010 at each bank, except the invertivore guild at the WFGB showed a significantly lower difference in biomass in 2010 (Table 10.4.16).

The interaction of bank and year on trophic guild biomass was analyzed using a two-way ANOVA (Table 10.4.17). The herbivore guild showed no significant difference between bank or year, and no significant interaction. The piscivore guild showed no significant difference between bank or year, but a significant interaction existed (α=0.005, P-value=0.0288). The invertivore guild showed no significant difference in bank, but a significant difference between years (α=0.005, P-value=0.0032), with a significiant interaction (α=0.005, P-value=0.0151). The planktivore guild showed no significant difference between bank, but there was a significant difference between years (α=0.005, P-value=0.0231), with no significant interaction.

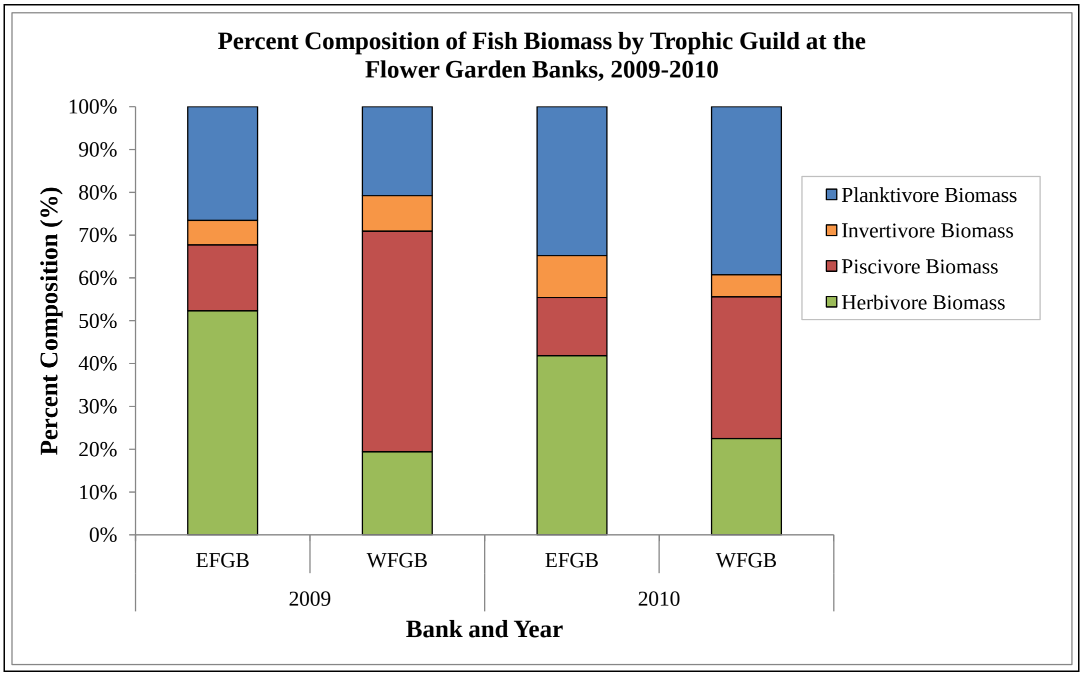


Figure 10.4.3. Percent composition of biomass for each trophic guild by bank and year.

Table 10.4.16.

Comparison of Biomass (g/m²) of Herbivores, Piscivores, Invertivores, and Planktivores between the EFGB and WFGB in 2009 and 2010

S = Significant, NS = Not significant

Category	**2009**				**2010**			
	EFGB	**WFGB**	**P-value**	**Significance**	**EFGB**	**WFGB**	**P-value**	**Significance**
Herbivore Biomass	84.65	26.15	0.41	NS	30.51	19.60	0.095	NS
Piscivore Biomass	24.98	69.56	0.51	NS	9.96	28.83	**0.0074**	**S**
Invertivore Biomass	9.27	11.12	0.17	NS	7.12	4.49	**0.0401**	**S**
Planktivore Biomass	42.97	28.12	0.36	NS	25.40	34.25	0.80	NS

Table 10.4.17.

Two-way ANOVA for Trophic Guild Biomass (g/m²), with Fixed Factors of Bank and Year

DF=Degrees of freedom, SS=Sum of squares, MS=Mean of squares, Sig=Significance; NS= Not significant, and S= Significant

Trophic Guild	Variance Source	DF	SS	MS	Sig.	P-value
Herbivore	Model	3	0.688766	0.229589		
	Bank	1	0.37849852		NS	0.0997
	Year	1	0.28722552		NS	0.1508
	Bank x Year	1	0.01110363		NS	0.7765
	Error	95	13.010032	0.136948		
	C. Total	98	13.698798			
Piscivore	Model	3	2.376345	0.792115		
	Bank	1	0.4843872		NS	0.2488
	Year	1	0.0509231		NS	0.7076
	Bank x Year	1	1.7737354		S	**0.0288**
	Error	95	34.177862	0.359767		
	C. Total	98	36.554207			
Invertivore	Model	3	1.767507	0.589169		
	Bank	1	0.0311178		NS	0.5993
	Year	1	1.0212366		S	**0.0032**
	Bank x Year	1	0.6855067		S	**0.0151**
	Error	95	10.638045	0.111979		
	C. Total	98	12.405553			
Planktivore	Model	3	1.954696	0.651565		
	Bank	1	0.1831716		NS	0.4539
	Year	1	1.7283919		S	**0.0231**
	Bank x Year	1	0.0421571		NS	0.7191
	Error	95	30.770688	0.323902		
	C. Total	98	32.725385			

Biomass of each species was compared between banks for 2009 and 2010 (Table 10.4.18). Significant differences were only observed in species from the herbivorous and piscivorous fish guilds in 2009, whereas all trophic guilds possessed species with significant differences in biomass between banks in 2010. In 2009, the significantly different herbivorous fish biomasses include Chub (*Kyphosus incisor* / *Kyphosus sectatrix*, α=0.005, P-value=0.0043) and Black Durgon (*Melichthys niger*, α=0.005, P-value=0.0186), and the piscivorous fishes included Dog Snapper (*Lutjanus jocu*, α=0.005, P-value=0.0239), Great Barracuda (*Sphyraena barracuda*, α=0.005, P-value=0.0386), and Bonnetmouth (*Emmelichthyops atlanticus*, α=0.005, P-value=0.0489). In 2010, the significantly different herbivorous fish biomasses include Bi-Color Damselfish (*Stegastes partitus*, α=0.005, P-value=0.0216), Stoplight Parrotfish (*Sparisoma viride*, α=0.005, P-value=0.0231), the piscivorous Great Barracuda (*Sphyraena barracuda*, α=0.005, P-value=0.0207), the invertivorous Spotfin Butterflyfish (*Chaetodon ocellatus*, α=0.005, P-value=0.0363), and the Creole Wrasse (*Clepticus parrae*, α=0.005, P-value=0.0431).

Table 10.4.18.

Biomass (g/m^2) of Each Species by Trophic Guild with P-values Shown Where Significant Differences Occur

NS = Not significant

Trophic Guild	**Species**	**2009**			**2010**		
		Biomass g/m^2			**Biomass g/m^2**		
		EFGB	**WFGB**	**P-value**	**EFGB**	**WFGB**	**P-value**
Herbivores	All Herbivores	84.65	26.15		30.51	19.60	
	Pomacentridae: *Stegastes variabilis* (Damselfish, Cocoa)	0.04	0.06	NS	0.10	0.17	NS
	Kyphosidae: *Kyphosus incisor / Kyphosus sectatrix* (Chub)	71.08	2.88	**0.0043**	10.07	3.72	NS
	Scaridae: *Scarus vetula* (Parrotfish, Queen)	3.10	4.61	NS	4.39	3.95	NS
	Pomacentridae: *Stegastes partitus* (Damselfish, Bi-color)	0.55	0.27	NS	0.20	0.08	**0.0216**
	Acanthuridae: *Acanthurus coeruleus* (Tang, Blue)	3.79	5.34	NS	3.00	2.97	NS
	*Atherinopsidae: Menidiina*e sp. (Silversides)	0.59	0.00	NS	0.00	0.00	NS
	Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	0.15	0.29	NS	0.03	0.01	NS
	Pomacanthidae: *Holacanthus ciliaris* (Angelfish, Queen)	0.30	0.98	NS	0.00	0.44	NS
	Blenniidae: *Ophioblennius macclurei* (Blenny, Redlip)	0.01	0.02	NS	0.00	0.00	NS
	Scaridae: *Sparisoma aurofrenatum* (Parrotfish, Redband)	0.18	0.36	NS	0.48	0.34	NS
	Pomacentridae: *Microspathodon chrysurus* (Damselfish, Yellowtail)	0.24	0.50	NS	0.27	0.27	NS
	Scaridae: *Sparisoma viride* (Parrotfish, Stoplight)	2.99	4.96	NS	6.12	2.88	**0.0231**
	Acanthuridae: *Acanthurus bahianus* (Surgeonfish, Ocean)	0.18	0.14	NS	0.53	0.62	NS
	Balistidae: *Melichthys niger* (Durgon, Black)	1.64	6.60	**0.0186**	3.12	3.78	NS
	Scaridae: *Scarus taeniopterus*	0.11	0.09	NS	2.12	0.80	NS

Trophic Guild	**Species**	**2009**			**2010**		
		Biomass g/m²			**Biomass g/m²**		
		EFGB	**WFGB**	**P-value**	**EFGB**	**WFGB**	**P-value**
	(Parrotfish, Princess)						
	Pomacentridae: *Stegastes adustus* (Damselfish, Dusky)	0.00	0.02	NS	0.01	0.01	NS
	Scaridae: *Sparisoma atomarium* (Parrotfish, Greenblotch)	0.00	0.00	NS	0.00	0.00	NS
	Gobiidae: *Gnatholepis thompsoni* (Goby, Goldspot)	0.00	0.00	NS	0.00	0.00	NS
	Scaridae: *Scarus iseri* (Parrotfish, Striped)	0.00	0.00	NS	0.08	0.00	NS
Piscivores	All Piscivores	24.98	69.56		9.96	28.83	
	Lutjanidae: *Lutjanus jocu* (Snapper, Dog)	1.27	0.00	**0.0239**	0.00	2.39	NS
	Serranidae: *Mycteroperca interstitialis* (Grouper, Yellowmouth)	0.85	0.24	NS	0.67	0.23	NS
	Serranidae: *Mycteroperca tigris* (Grouper, Tiger)	1.44	0.00	NS	0.31	4.10	NS
	Carangidae: *Caranx latus* (Jack, Horse-eye)	14.63	3.24	NS	0.00	3.64	NS
	Carangidae: *Caranx lugubris* (Jack, Black)	0.69	1.07	NS	2.16	0.00	NS
	Serranidae: *Cephalopholis cruentata* (Graysby)	0.24	0.53	NS	0.50	0.59	NS
	Sphyraenidae: *Sphyraena barracuda* (Barracuda, Great)	1.79	3.56	**0.0386**	6.14	17.68	**0.0207**
	Serranidae: *Mycteroperca bonaci* (Grouper, Black)	0.14	0.00	NS	0.00	0.13	NS
	Serranidae: *Mycteroperca phenax* (Scamp)	0.07	0.14	NS	0.02	0.00	NS
	Inermiidae: *Emmelichthyops atlanticus* (Bonnetmouth)	1.85	0.00	**0.0489**	0.00	0.00	NS
	Carangidae: *Carangoides ruber* (Jack, Bar)	0.52	0.10	NS	0.15	0.06	NS
	Carangidae: *Caranx crysos* (Blue runner)	0.37	0.35	NS	0.00	0.00	NS
	Muraenidae: *Gymnothorax meleagris* (Moray, Spotted)	1.12	1.12	NS	0.00	0.02	NS
	Aulostomidae: *Aulostomus maculatus* (Trumpetfish)	0.00	0.01	NS	0.00	0.00	NS
	Carangidae: *Elagatis bipinnulata* (Rainbow runner)	0.00	59.20	NS	0.00	0.00	NS
	Serranidae: *Mycteroperca venenosa* (Grouper, Yellowfin)	0.00	0.00	NS	0.00	0.00	NS
Invertivores	All Invertivores	9.27	11.12		7.12	4.49	
	Pomacentridae: *Chromis multilineata* (Chromis, Brown)	4.04	1.63	NS	1.65	1.23	NS

Trophic Guild	Species	2009			2010		
		Biomass g/m^2			Biomass g/m^2		
		EFGB	**WFGB**	**P-value**	**EFGB**	**WFGB**	**P-value**
	Labridae: *Thalassoma lucasanum* (Wrasse, Bluehead)	0.25	0.36	NS	0.21	0.13	NS
	Pomacentridae: *Stegastes planifrons* (Damselfish, Three-spot)	0.18	0.49	NS	0.20	0.25	NS
	Cirrhitidae: *Amblycirrhitus pinos* (Hawkfish, Redspotted)	0.00	0.00	NS	0.00	0.00	NS
	Tetraodontidae: Canthigaster *rostrata* (Puffer, Sharpnose)	0.08	0.09	NS	0.16	0.07	NS
	Labridae: *Bodianus rufus* (Hogfish, Spanish)	0.28	0.61	NS	0.41	0.64	NS
	Chaetodontidae: *Chaetodon ocellatus* (Butterflyfish, Spotfin)	0.20	0.11	NS	0.00	0.08	**0.0363**
	Pomacanthidae: *Holacanthus tricolor* (Angelfish, Rock Beauty)	0.37	0.56	NS	0.09	0.03	NS
	Chaetodontidae: *Chaetodon sedentarius* (Butterflyfish, Reef)	0.16	0.32	NS	0.20	0.28	NS
	Monacanthidae: *Cantherhines pullus* (Filefish, Orange Spotted)	0.08	0.07	NS	0.01	0.00	NS
	Balistidae: *Canthidermis sufflamen* (Triggerfish, Ocean)	0.72	0.32	NS	0.20	0.00	NS
	Ostraciidae: *Lactophrys triqueter* (Trunkfish, Smooth)	0.08	0.21	NS	0.13	0.03	NS
	Labridae: *Halichoeres maculipinna* (Wrasse, Clown)	0.05	0.02	NS	0.00	0.00	NS
	Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	0.09	0.58	NS	0.03	0.07	NS
	Gobiidae: *Elacatinus oceanops* (Goby, Neon)	0.00	0.00	NS	0.01	0.00	NS
	Pomacanthidae: *Pomacanthus paru* (Angelfish, French)	2.06	0.32	NS	2.04	0.24	NS
	Serranidae: *Epinephelus adscensionis* (Hind, Rock)	0.15	0.00	NS	0.08	0.00	NS
	Serranidae: *Epinephelus guttatus* (Hind, Red)	0.01	0.00	NS	0.00	0.00	NS
	Labridae: *Halichoeres garnoti* (Wrasse, Yellowhead)	0.02	0.08	NS	0.01	0.04	NS
	Mullidae: *Pseudupeneus maculatus* (Goatfish, Spotted)	0.05	0.00	NS	0.00	0.00	NS
	Ostraciidae: *Acanthostracion polygonius* (Cowfish, Honeycomb)	0.09	0.54	NS	0.19	0.00	NS
	Chaetodontidae: *Prognathodes aculeatus* (Butterflyfish, Longsnout)	0.01	0.09	NS	0.02	0.01	NS

Trophic Guild	Species	2009			2010		
		Biomass g/m²			Biomass g/m²		
		EFGB	WFGB	P-value	EFGB	WFGB	P-value
	Labridae: *Bodianus pulchellus* (Hogfish, Spotfin)	0.00	0.00	NS	0.00	0.00	NS
	Ostraciidae: *Lactophrys bicaudalis* (Trunkfish, Spotted)	0.00	0.05	NS	0.00	0.00	NS
	Lutjanidae: *Lutjanus agennes* (Snapper, Grey)	0.00	0.94	NS	0.48	0.82	NS
	Apogonidae: *Apogon* sp. (Cardinal fish sp.)	0.00	0.00	NS	0.00	0.00	NS
	Holocentridae: *Holocentrus rufus* (Squirrelfish, Longspine)	0.00	0.16	NS	0.05	0.06	NS
	Diodontidae: *Diodon holocanthus* (Ballonfish)	0.00	0.06	NS	0.00	0.05	NS
	Monacanthidae: *Cantherhines macrocerus* (Filefish, Whitespotted)	0.00	0.27	NS	0.23	0.00	NS
	Mullidae: *Mulloidichthys martinicus* (Goatfish, Yellow)	0.00	0.45	NS	0.08	0.00	NS
	Muraenidae: *Gymnothorax miliaris* (Moray, Goldentail)	0.00	0.00	NS	0.00	0.00	NS
	Dasyatidae: *Dasyatis americana* (Stingray, Southern)	0.00	1.81	NS	0.00	0.00	NS
	Labridae: *Halichoeres radiatus* (Pudding wife)	0.00	0.01	NS	0.01	0.00	NS
	Labridae: *Halichoeres bivittatus* (Wrasse, Slippery Dick)	0.00	0.00	NS	0.00	0.00	NS
	Tetraodontidae: *Sphoeroides spengleri* (Puffer, Bandtail)	0.00	0.00	NS	0.00	0.00	NS
	Chaetodontidae: *Chaetodon striatus* (Butterflyfish, Banded)	0.00	0.00	NS	0.01	0.01	NS
	Balistidae: *Balistes vetula* (Triggerfish, Queen)	0.00	0.00	NS	0.63	0.00	NS
	Serranidae: *Liopropoma rubre* (Bass, Peppermint)	0.00	0.00	NS	0.00	0.00	NS
	Holocentridae: *holocentrus adscensionis* (Squirrelfish)	0.00	0.00	NS	0.00	0.00	NS
	Serranidae: *Cephalopholis fulva* (Grouper, Coney)	0.00	0.00	NS	0.00	0.00	NS
Planktivores	All Planktivores	42.97	28.12		25.40	34.25	
	Serranidae: *Paranthias furcifer* (Creolefish)	35.60	17.89	NS	23.80	33.29	NS
	Pomacentridae: *Chromis cyanea* (Chromis, Blue)	0.44	0.47	NS	0.30	0.16	NS
	Labridae: *Clepticus parrae* (Wrasse, Creole)	6.87	9.71	NS	1.28	0.71	**0.0431**
	Pomacentridae: *Chromis*	0.03	0.03	NS	0.02	0.07	NS

Trophic Guild	**Species**	**2009**			**2010**		
		Biomass g/m²			**Biomass g/m²**		
		EFGB	**WFGB**	**P-value**	**EFGB**	**WFGB**	**P-value**
	scotti (Reeffish, Purple)						
	Pomacentridae: *Chromis insolata* (Sunshinefish)	0.01	0.01	NS	0.01	0.01	NS
	Echeneidae: *Echeneidae* sp. (Remora)	0.03	0.00	NS	0.00	0.00	NS
	Lutjanidae: *Lutjanus argentiventris* (Snapper, Yellowtail)	0.00	0.00	NS	0.00	0.00	NS

When banks were compared between years (Table 10.4.19), significant differences were for five herbivores, Cocoa Damselfish (*Stegastes variabilis*, α=0.005, P-value=0.0387), Chub (*Kyphosus incisor* / *Kyphosus sectatrix*, α=0.005, P-value=0.0315), Bi-Color Damselfish (*Stegastes partitus*, α=0.005, P-value=0.041), Redlip Blenny (*Ophioblennius macclurei*, α=0.005, P-value=0.0467), and Princess Parrotfish (*Scarus taeniopterus*, α=0.005, P-value=0.0088), and four piscivores Dog Snapper (*Lutjanus jocu*, α=0.005, P-value=0.0239), Horse-Eye Jack (*Caranx latus*, α=0.005, P-value=0.0086), Great Barracuda (*Sphyraena barracuda*, α=0.005, P-value=0.0029), and Bonnetmouth (*Emmelichthyops atlanticus*, α=0.005, P-value=0.0486). At the WFGB, significant difference in biomass between 2009 and 2010 were found for five herbivores, Cocoa Damselfish (*Stegastes variabilis*, α=0.005, P-value=0.0247), Bi-Color Damselfish (*Stegastes partitus*, α=0.005, P-value=0.0008), Redlip Blenny (*Ophioblennius macclurei*, α=0.005, P-value=0.0153), Stoplight Parrotfish (*Sparisoma viride*, α=0.005, P-value=0.0234), and Princess Parrotfish (*Scarus taeniopterus*, α=0.005, P-value=0.0463), three piscivoresTiger Grouper (*Mycteroperca tigris*, α=0.005, P-value=0.0129), Black Jack (*Caranx lugubris*, α=0.005, P-value=0.006), and Great Barracuda (*Sphyraena barracuda*, α=0.005, P-value=0.0007), two invertivores, Rock Beauty (*Holacanthus tricolor*, α=0.005, P-value=0.0137) and Honeycomb Cowfish (*Acanthostracion polygonius*, α=0.005, P-value=0.0471), and two planktivoresBlue Chromis (*Chromis cyanea*, α=0.005, P-value=0.0308) and Creole Wrasse (*Clepticus parrae*, α=0.005, P-value=0.0003).

Table 10.4.19.

Biomass Comparisons Between Years

Significant differences are shown in bold; NS = Not significant

Trophic Guild	Species	EFGB			WFGB		
		Biomass g/m^2			Biomass g/m^2		
		2009	2010	P-value	2009	2010	P-value
Herbivores	All Herbivores	84.65	30.51		26.15	19.60	
	Pomacentridae: *Stegastes variabilis* (Damselfish, Cocoa)	0.04	0.10	**0.0387**	0.06	0.17	**0.0247**
	Kyphosidae: *Kyphosus incisor / Kyphosus sectatrix* (Chub)	71.08	10.07	**0.0315**	2.88	3.72	NS
	Scaridae: *Scarus vetula* (Parrotfish, Queen)	3.10	4.39	NS	4.61	3.95	NS
	Pomacentridae: *Stegastes partitus* (Damselfish, Bi-color)	0.55	0.20	**0.041**	0.27	0.08	**0.0008**
	Acanthuridae: *Acanthurus coeruleus* (Tang, Blue)	3.79	3.00	NS	5.34	2.97	NS
	Atherinopsidae: *Menidiina*e sp. (Silversides)	0.59	0.00	NS	0.00	0.00	NS
	Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	0.15	0.03	NS	0.29	0.01	NS
	Pomacanthidae: *Holacanthus ciliaris* (Angelfish, Queen)	0.30	0.00	NS	0.98	0.44	NS
	Blenniidae: *Ophioblennius macclurei* (Blenny, Redlip)	0.01	0.00	**0.0467**	0.02	0.00	**0.0153**
	Scaridae: *Sparisoma aurofrenatum* (Parrotfish, Redband)	0.18	0.48	NS	0.36	0.34	NS
	Pomacentridae: *Microspathodon chrysurus* (Damselfish, Yellowtail)	0.24	0.27	NS	0.50	0.27	NS
	Scaridae: *Sparisoma viride* (Parrotfish, Stoplight)	2.99	6.12	NS	4.96	2.88	**0.0234**
	Acanthuridae: *Acanthurus bahianus* (Surgeonfish, Ocean)	0.18	0.53	NS	0.14	0.62	NS
	Balistidae: *Melichthys niger* (Durgon, Black)	1.64	3.12	NS	6.60	3.78	NS
	Scaridae: *Scarus taeniopterus* (Parrotfish, Princess)	0.11	2.12	**0.0088**	0.09	0.80	**0.0463**
	Pomacentridae: *Stegastes adustus* (Damselfish, Dusky)	0.00	0.01	NS	0.02	0.01	NS
	Scaridae: *Sparisoma atomarium* (Parrotfish, Greenblotch)	0.00	0.00	NS	0.00	0.00	NS
	Gobiidae: *Gnatholepis thompsoni* (Goby, Goldspot)	0.00	0.00	NS	0.00	0.00	NS
	Scaridae: *Scarus iseri* (Parrotfish, Striped)	0.00	0.08	NS	0.00	0.00	NS
Piscivores	All Piscivores	24.98	9.96		69.56	28.83	
	Lutjanidae: *Lutjanus jocu* (Snapper, Dog)	1.27	0.00	**0.0239**	0.00	2.39	NS
	Serranidae: *Mycteroperca interstitialis* (Grouper, Yellowmouth)	0.85	0.67	NS	0.24	0.23	NS

Trophic Guild	**Species**	**EFGB**			**WFGB**		
		Biomass g/m^2			**Biomass g/m^2**		
		2009	**2010**	**P-value**	**2009**	**2010**	**P-value**
	Serranidae: *Mycteroperca tigris* (Grouper, Tiger)	1.44	0.31	NS	0.00	4.10	**0.0129**
	Carangidae: *Caranx latus* (Jack, Horse-eye)	14.63	0.00	**0.0086**	3.24	3.64	NS
	Carangidae: *Caranx lugubris* (Jack, Black)	0.69	2.16	NS	1.07	0.00	**0.006**
	Serranidae: *Cephalopholis cruentata* (Graysby)	0.24	0.50	NS	0.53	0.59	NS
	Sphyraenidae: *Sphyraena barracuda* (Barracuda, Great)	1.79	6.14	**0.0029**	3.56	17.68	**0.0007**
	Serranidae: *Mycteroperca bonaci* (Grouper, Black)	0.14	0.00	NS	0.00	0.13	NS
	Serranidae: *Mycteroperca phenax* (Scamp)	0.07	0.02	NS	0.14	0.00	NS
	Inermiidae: *Emmelichthyops atlanticus* (Bonnetmouth)	1.85	0.00	**0.0486**	0.00	0.00	NS
	Carangidae: *Carangoides rube*r (Jack, Bar)	0.52	0.15	NS	0.10	0.06	NS
	Carangidae: *Caranx crysos* (Blue runner)	0.37	0.00	NS	0.35	0.00	NS
	Muraenidae: *Gymnothorax meleagris* (Moray, Spotted)	1.12	0.00	NS	1.12	0.02	NS
	Aulostomidae: *Aulostomus maculatus* (Trumpetfish)	0.00	0.00	NS	0.01	0.00	NS
	Carangidae: *Elagatis bipinnulata* (Rainbow runner)	0.00	0.00	NS	59.20	0.00	NS
	Serranidae: *Mycteroperca venenosa* (Grouper, Yellowfin)	0.00	0.00	NS	0.00	0.00	NS
Invertivores	All Invertivores	9.27	7.12		11.12	4.49	
	Pomacentridae: *Chromis multilineata* (Chromis, Brown)	4.04	1.65	NS	1.63	1.23	NS
	Labridae: *Thalassoma lucasanum* (Wrasse, Bluehead)	0.25	0.21	NS	0.36	0.13	NS
	Pomacentridae: *Stegastes planifrons* (Damselfish, Three-spot)	0.18	0.20	NS	0.49	0.25	NS
	Cirrhitidae: *Amblycirrhitus pinos* (Hawkfish, Redspotted)	0.00	0.00	NS	0.00	0.00	NS
	Tetraodontidae: Canthigaster *rostrata* (Puffer, Sharpnose)	0.08	0.16	NS	0.09	0.07	NS
	Labridae: *Bodianus rufus* (Hogfish, Spanish)	0.28	0.41	NS	0.61	0.64	NS
	Chaetodontidae: *Chaetodon ocellatus* (Butterflyfish, Spotfin)	0.20	0.00	NS	0.11	0.08	NS
	Pomacanthidae: *Holacanthus tricolor* (Angelfish, Rock Beauty)	0.37	0.09	NS	0.56	0.03	**0.0137**
	Chaetodontidae: *Chaetodon sedentarius* (Butterflyfish, Reef)	0.16	0.20	NS	0.32	0.28	NS
	Monacanthidae: *Cantherhines pullus* (Filefish, Orange Spotted)	0.08	0.01	NS	0.07	0.00	NS
	Balistidae: *Canthidermis sufflamen*	0.72	0.20	NS	0.32	0.00	NS

Trophic Guild	Species	EFGB			WFGB		
		Biomass g/m²			Biomass g/m²		
		2009	2010	P-value	2009	2010	P-value
	(Triggerfish, Ocean)						
	Ostraciidae: *Lactophrys triqueter* (Trunkfish, Smooth)	0.08	0.13	NS	0.21	0.03	NS
	Labridae: *Halichoeres maculipinna* (Wrasse, Clown)	0.05	0.00	NS	0.02	0.00	NS
	Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	0.09	0.03	NS	0.58	0.07	NS
	Gobiidae: *Elacatinus oceanops* (Goby, Neon)	0.00	0.01	NS	0.00	0.00	NS
	Pomacanthidae: *Pomacanthus paru* (Angelfish, French)	2.06	2.04	NS	0.32	0.24	NS
	Serranidae: *Epinephelus adscensionis* (Hind, Rock)	0.15	0.08	NS	0.00	0.00	NS
	Serranidae: *Epinephelus guttatus* (Hind, Red)	0.01	0.00	NS	0.00	0.00	NS
	Labridae: *Halichoeres garnoti* (Wrasse, Yellowhead)	0.02	0.01	NS	0.08	0.04	NS
	Mullidae: *Pseudupeneus maculatus* (Goatfish, Spotted)	0.05	0.00	NS	0.00	0.00	NS
	Ostraciidae: *Acanthostracion polygonius* (Cowfish, Honeycomb)	0.09	0.19	NS	0.54	0.00	**0.0471**
	Chaetodontidae: *Prognathodes aculeatus* (Butterflyfish, Longsnout)	0.01	0.02	NS	0.09	0.01	NS
	Labridae: *Bodianus pulchellus* (Hogfish, Spotfin)	0.00	0.00	NS	0.00	0.00	NS
	Ostraciidae: *Lactophrys bicaudalis* (Trunkfish, Spotted)	0.00	0.00	NS	0.05	0.00	NS
	Lutjanidae: *Lutjanus agennes* (Snapper, Grey)	0.00	0.48	NS	0.94	0.82	NS
	Apogonidae: *Apogon* sp. (Cardinal fish sp.)	0.00	0.00	NS	0.00	0.00	NS
	Holocentridae: *Holocentrus rufus* (Squirrelfish, Longspine)	0.00	0.05	NS	0.16	0.06	NS
	Diodontidae: *Diodon holocanthus* (Ballonfish)	0.00	0.00	NS	0.06	0.05	NS
	Monacanthidae: *Cantherhines macrocerus* (Filefish, Whitespotted)	0.00	0.23	NS	0.27	0.00	NS
	Mullidae: *Mulloidichthys martinicus* (Goatfish, Yellow)	0.00	0.08	NS	0.45	0.00	NS
	Muraenidae: *Gymnothorax miliaris* (Moray, Goldentail)	0.00	0.00	NS	0.00	0.00	NS
	Dasyatidae: *Dasyatis americana* (Stingray, Southern)	0.00	0.00	NS	1.81	0.00	NS
	Labridae: *Halichoeres radiatus* (Pudding wife)	0.00	0.01	NS	0.01	0.00	NS
	Labridae: *Halichoeres bivittatus* (Wrasse, Slippery Dick)	0.00	0.00	NS	0.00	0.00	NS
	Tetraodontidae: *Sphoeroides spengleri* (Puffer, Bandtail)	0.00	0.00	NS	0.00	0.00	NS
	Chaetodontidae: *Chaetodon striatus*	0.00	0.01	NS	0.00	0.01	NS

Trophic Guild	Species	EFGB			WFGB		
		Biomass g/m^2			Biomass g/m^2		
		2009	**2010**	**P-value**	**2009**	**2010**	**P-value**
	(Butterflyfish, Banded)						
	Balistidae: *Balistes vetula* (Triggerfish, Queen)	0.00	0.63	NS	0.00	0.00	NS
	Serranidae: *Liopropoma rubre* (Bass, Peppermint)	0.00	0.00	NS	0.00	0.00	NS
	Holocentridae: *holocentrus adscensionis* (Squirrelfish)	0.00	0.00	NS	0.00	0.00	NS
	Serranidae: *Cephalopholis fulva* (Grouper, Coney)	0.00	0.00	NS	0.00	0.00	NS
Planktivores	All Planktivores	42.97	25.40		28.12	34.25	
	Serranidae: *Paranthias furcifer* (Creolefish)	35.60	23.80	NS	17.89	33.29	NS
	Pomacentridae: *Chromis cyanea* (Chromis, Blue)	0.44	0.30	NS	0.47	0.16	**0.0308**
	Labridae: *Clepticus parrae* (Wrasse, Creole)	6.87	1.28	NS	9.71	0.71	**0.0003**
	Pomacentridae: *Chromis scotti* (Reeffish, Purple)	0.03	0.02	NS	0.03	0.07	NS
	Pomacentridae: *Chromis insolata* (Sunshinefish)	0.01	0.01	NS	0.01	0.01	NS
	Echeneidae: *Echeneidae* sp. (Remora)	0.03	0.00	NS	0.00	0.00	NS
	Lutjanidae: *Lutjanus argentiventris* (Snapper, Yellowtail)	0.00	0.00	NS	0.00	0.00	NS

10.4.6. Diurnal Abundance Patterns

Previous studies have observed differences in the behaviors of several species of fish in the morning versus the afternoon (Zimmer et al. 2010). Three species of interest included Great Barracuda (*Sphyraena barracuda*), Creole Wrasse (*Clepticus parrae*), and Creolefish (*Paranthias furcifer*) as they may exhibit differences in behaviors throughout the day, resulting in disparate data on morning dives compared to afternoon dives. Yearly comparisons were made between the abundance of these species between the time of day (morning or afternoon) and bank. At the EFGB in 2009, 11 surveys were conducted in the morning (Dawn to 12:00 PM) and 13 surveys were conducted in the afternoon (12:00 PM to Dusk). At the WFGB in 2009, 6 surveys were conducted in the morning and 18 in the afternoon. At the EFGB in 2010, 8 surveys were conducted in the morning and 17 in the afternoon. At the WFGB in 2010, 19 surveys were conducted in the morning and 8 in the afternoon. No significant differences were found between time of surveys for the three species, though a difference was found for Great Barracuda (*Sphyraena barracuda*) between banks in 2009 (Table 10.4.20).

Table 10.4.20

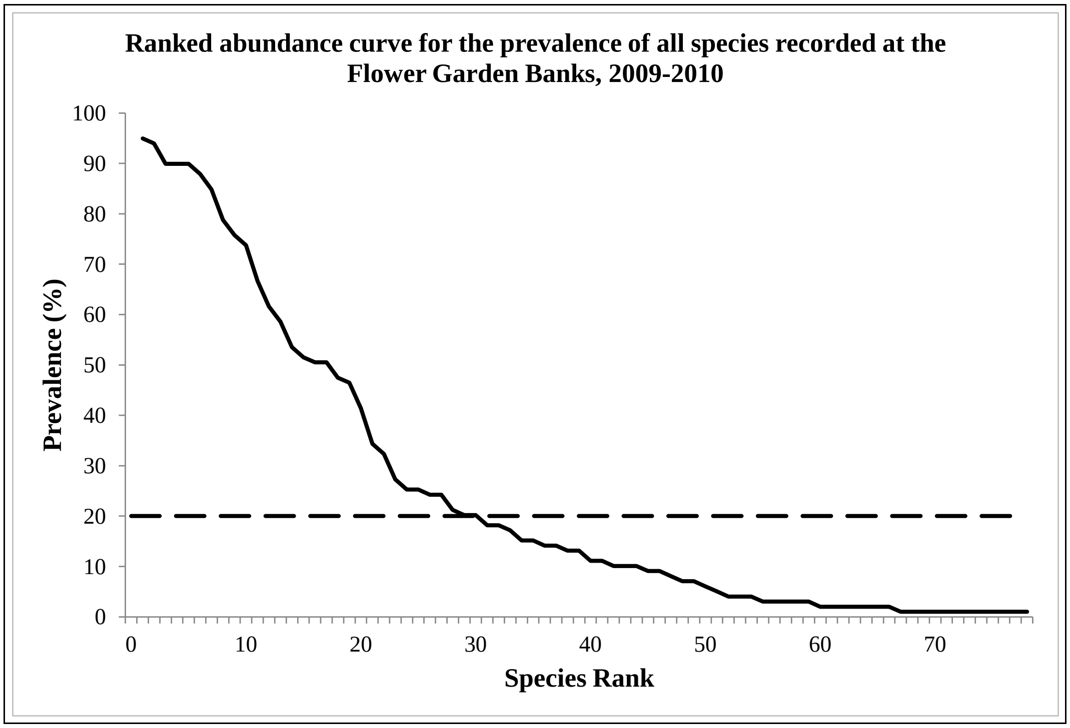
Two-way ANOVA for Great Barracuda Abundance, with Fixed Factors of Bank and Time of Day

DF=Degrees of freedom, SS=Sum of squares, MS=Mean of squares, Sig=Significant, P=Probability, NS=Not significant, and S=Significant

Var. Source	**2009**					**2010**				
	DF	**SS**	**MS**	**Sig.**	**P-value**	**DF**	**SS**	**MS**	**Sig.**	**P-value**
Model	3	0.269392	0.089797			3	0.1230975	0.041033		
Bank	1	0.161878		S	**0.0101**	1	0.12219133		NS	0.1692
Time of Day	1	0.000642		NS	0.8663	1	0.02584458		NS	0.5239
Bank x Time	1	0.031294		NS	0.2434	1	0.0001781		NS	0.9577
Error	44	0.98477	0.022381			48	3.0099847	0.062708		
C. Total	47	1.254162				51	3.1330823			

10.4.7. Prevalent Compared with Rare Species

A rank abundance was used to determine and remove “rare” species. Species were considered “rare” if they were recorded in less than 20% of samples. “Prevalent” species occurred in ≥20% of samples (Figure 10.4.4). A total of 30 species was considered “prevalent” using this method (Table 10.4.21).



The dashed line represents the 20% sighting frequency threshold in determining "prevalent" compared to "rare" species.

Figure 10.4.4. Ranked abundance curve for the prevalence of all species recorded during the 2009 and 2010 surveys.

Table 10.4.21.

Ranked Abundance of "Prevalent" Species

Rank	**Species**	**Trophic Guild**	**Percent with rare removed**
1	Serranidae: *Paranthias furcifer* (Creolefish)	PL	95
2	Labridae: *Thalassoma lucasanum* (Wrasse, Bluehead)	I	94
3	Pomacentridae: *Chromis multilineata* (Chromis, Brown)	I	90
4	Pomacentridae: *Stegastes partitus* (Damselfish, Bi-color)	H	90
5	Acanthuridae: *Acanthurus coeruleus* (Tang, Blue)	H	90
6	Tetraodontidae: *Canthigaster rostrata* (Puffer, Sharpnose)	I	88
7	Labridae: *Bodianus rufus* (Hogfish, Spanish)	I	85
8	Pomacentridae: *Chromis cyanea* (Chromis, Blue)	PL	79
9	Scaridae: *Scarus vetula* (Parrotfish, Queen)	H	76
10	Labridae: *Clepticus parrae* (Wrasse, Creole)	PL	74
11	Pomacentridae: *Stegastes planifrons* (Damselfish, Three-spot)	I	67
12	Sphyraenidae: *Sphyraena barracuda* (Barracuda, Great)	P	62
13	Scaridae: *Sparisoma viride* (Parrotfish, Stoplight)	H	59
14	Balistidae: *Melichthys niger* (Durgon, Black)	H	54
15	Pomacentridae: *Stegastes variabilis* (Damselfish, Cocoa)	H	52
16	Kyphosidae: *Kyphosus incisor / Kyphosus sectatrix* (Chub)	H	51
17	Chaetodontidae: *Chaetodon sedentarius* (Butterflyfish, Reef)	I	51
18	Pomacentridae: *Chromis scotti* (Reeffish, Purple)	PL	47
19	Serranidae: *Cephalopholis cruentata* (Graysby)	P	46
20	Pomacentridae: *Microspathodon chrysurus* (Damselfish, Yellowtail)	H	41
21	Scaridae: *Sparisoma aurofrenatum* (Parrotfish, Redband)	H	34
22	Pomacentridae: *Chromis insolata* (Sunshinefish)	PL	32
23	Acanthuridae: *Acanthurus bahianus* (Surgeonfish, Ocean)	H	27
24	Blenniidae: *Ophioblennius macclurei* (Blenny, Redlip)	H	25
25	Pomacanthidae: *Holacanthus tricolor* (Angelfish, Rock Beauty)	I	25
26	Serranidae: *Mycteroperca interstitialis* (Grouper, Yellowmouth)	P	24
27	Ostraciidae: *Lactophrys triqueter* (Trunkfish, Smooth)	I	24
28	Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	I	21
29	Scaridae: *Scarus taeniopterus* (Parrotfish, Princess)	H	20
30	Labridae: *Halichoeres garnoti* (Wrasse, Yellowhead)	I	20

10.5. FISH SURVEYS DISCUSSION

Perhaps two of the most important factors that shape the fish assemblages at the FGB are: (1) they occur near the northern latitudinal limit of coral reefs and are remote from other tropical reefs and (2) they occur in close proximity to offshore hydrocarbon production platforms. As a remote outpost of Caribbean coral reef biota, the fish assemblage has been reported to be low in diversity yet high in biomass (Pattengill-Semmens and Gittings 2003; Zimmer et al. 2010). They also differ from fish assemblages in other reef and hard bottom systems in the Gulf of Mexico and Caribbean in that the have limited representation by lutjanids and haemulids (Rooker et al. 1997). The large number of oil and gas production platforms in the Gulf of Mexico, as well as the addition of mooring buoys at the banks in 1990, may have promoted the dispersal of additional fish species and allowed some to reach the FGB and establish themselves (Boland et al. 1983; Rooker et al. 1997; Gittings 1998).

Fishing pressure, water quality (including temperature and planktonic composition), and current flow patterns also affect fish assemblages at the FGB to varying degrees. Since the late 1800's, fishermen have conducted long-line fishing around the Flower Gardens (Scarborough-Bull 1988). Since 1992, commercial fishing with bottom long-lines, traps, nets, and bottom trawls are prohibited within the sanctuary's boundaries. Although hand-line and hook and line fishing, including bandit reels (powered reels), are allowed within the boundaries, the distance from shore does reduce fishing pressure to some extent, therefore providing some protection to fish populations.

The stationary fish surveys conducted in 2009 and 2010 revealed a thriving reef fish assemblage, as observed in previous annual monitoring surveys (Precht et al. 2006; Zimmer et al. 2010) and in other reef-fish surveys conducted at the FGB (Rooker et al. 1997). But numerous other approaches have been used over the years to collect fish data from the Flower Garden Banks.

Extensive surveys conducted in 1980–1982 by Boland et al. (1983) used, among other things, remote video to collect data on fish assemblages. A decade later, when the Reef Environmental Education Foundation began surveys at the Flower Garden Banks, the roving diver technique (RDT) was used (Pattengill-Semmens and Gittings 2003). Rooker et al. (1997) and Pattengill et al. (1998) were the first to use the stationary visual census technique of Bohnsack and Bannerot (1986) at the Flower Gardens.

Each of the techniques employed have strengths and weaknesses. Comparisons of visual census techniques (e.g., Bortone et al. 1989) have revealed, for example, that the RDT produces good data on diversity and sighting frequency, but is not as well suited as stationary surveys for recording fish counts, sizes, or densities.

The FGB fish populations on the reef cap were dominated by the families Pomacentridae, Labridae, Serranidae, and Scaridae. This was also found in previous monitoring (Precht et al. 2006; Zimmer et al. 2010). The pomacentrids were the most diverse, with 10 species. The labrids and serranids were represented by a moderate number of species. Creolefish (*Paranthias furcifer*) were one of the most abundant species on the reefs, along with large schools of creole wrasse (*Clepticus parrae*). Similar to other Caribbean coral reef communities, blue and brown chromis (*Chromis cyanea* and *C. multilineata*) were commonly seen in schools above coral formations. Also as expected in Caribbean communities, groups of female or male bluehead wrasse (*Thalassoma bifasciatum*) in intermediate or juvenile phases were regularly seen on diver surveys in low areas between and just above coral formations, with one or two males in close association. Although lower in number because of their solitary nature, Caribbean sharp-nose puffer (*Canthigaster rostrata*) actively explored crevices and low areas. The redlip blenny, (*Ophioblennius atlanticus*), was commonly seen perched on the face of coral formations.

Some species were likely underestimated because of the techniques used. Many blenny and goby species, for example, are small and cryptic. The stationary counting technique used here would underestimate their abundance and perhaps the number of species. Furthermore, surveys also intentionally excluded sand-covered bottom areas, so diver surveys were less likely to have recorded species associated with that habitat.

While invertivores were the dominant fish guild at the Flower Garden Banks, a healthy assemblage of herbivorous fishes was recorded. Herbivore populations appear to have responded to the drastic decline in *Diadema antillarum* at the FGB, which occurred in 1983 and 1984 (Gittings et al. 1992). As a group, acanthurids, scarids, and *Microspathodon chrysurus* were relatively high in density at both banks in 2009 and 2010. While the FGB has lower species richness (including fewer scarid species) and a lower overall abundance of herbivorous fishes than Caribbean reefs (Rezak et al. 1985; Dennis and Bright 1988), the percentages of acanthurids and scarids is similar to deep/fore reefs of far western Cuba and Akumal, Yucatan, Mexico (Table 10.5.1.; Claro and Cantelar Ramos 2003; Steneck and Lang 2003). The low algal cover reported here, despite the lack of an actively grazing *Diadema antillarum* population, may be the result of this apparently adaptive community of herbivores. Finally, algal farming pomacentrids were abundant as well. There were more of these gardeners recorded in 2009 than 2010 at the FGB.

While the species richness of reef-associated carnivores (certain serranids and lutjanids) was high, density values were somewhat low. The density of reef associated carnivores appears depressed in relation to previous studies. It is not possible, at this point, to determine whether this is due to recent fishing pressure (which is allowed within the FGBNMS by hook and line only).

Table 10.5.1.

Percentage of Fishes Observed in the Listed Families at Reefs around the Gulf of Mexico and the Caribbean Region

Combined herbivore percentages shown at bottom

Family	Maria La Gorda, Cuba	Akumal, Yucatan, Mexico	FGBNMS, USA
Acanthuridae	17%	22%	15%
Balistidae	37%	0%	9%
Chaetodontidae	7%	5%	9%
Lutjanidae	5%	7%	1%
Pomacanthidae	4%	2%	4%
Scaridae	25%	58%	24%
Serranidae	6%	6%	8%
Acanthuridae and Scaridae	42%	80%	39%

(Claro and Cantelar Ramos 2003; Steneck and Lang 2003; Precht et al. 2006)

CHAPTER 11.0: SEA URCHIN AND LOBSTER SURVEYS

11.1. SEA URCHIN AND LOBSTER SURVEYS METHODOLOGICAL RATIONALE

The long-spined sea urchin, *Diadema antillarum*, was an important herbivore on coral reefs throughout the Caribbean until 1983 and 1984. At that time, an unknown pathogen decimated populations throughout the region, including the FGBNMS. Since then, patchy but limited recovery has been documented in the region (Edmunds and Carpenter 2001). *Diadema antillarum* populations at the FGBNMS pre-1984 exceeded 1 individual/m^2 (hindcast surveys were made from archived transect photos taken during daytime hours, which would underestimate densities; Gittings et al. 1992; Aronson et al. 2005).

Lobsters are commercially important species throughout much of the Caribbean and Gulf of Mexico; however, population dynamics of Caribbean spiny lobster (*Panulirus argus*) in the FGBNMS are not well understood.

11.2. SEA URCHIN AND LOBSTER SURVEYS FIELD METHODS

Due to the nocturnal nature of these species, visual surveys were conducted at night, a minimum of 1.5 hours after sunset. In 2009 and 2010, surveys for *Diadema antillarum* (long-spined sea urchin), *Panulirus argus* (Caribbean spiny lobster) and *P. guttatus* (spotted spiny lobster) were conducted along the northern and eastern perimeter lines at the EFGB and along the southern and western boundaries at the WFGB. Two belt transects 2 m wide and 100 m long were surveyed by diver teams on each bank, thus totaling 400 m^2 per bank each year. Surveys began with the northeast corner at the EFGB study site and the southeast corner at the WFGB study site. All observed species of sea urchin and lobster were recorded.

Due to low sample abundance, only qualitative analyses were possible for the lobster and sea urchin surveys.

11.3. SEA URCHIN AND LOBSTER SURVEYS RESULTS

The number of individuals recorded during each survey in 2009 and 2010 are listed in Table 11.3.1. No lobsters were observed on surveys at either bank in 2009 or 2010. At the EFGB in 2009, one *Diadema antillarum* (0.25 per 100 m^2) was documented, and in 2010, two individuals (0.5 per 100 m^2) were documented. This correlates to very low densities of *Diadema antillarum* at the EFGB in 2009 (0.25 individuals/100 m^2) and 2010 (0.5 individuals/100 m^2).

Considerably more *Diadema antillarum* were found at the WFGB during this monitoring period. In 2009, 55 *Diadema antillarum* (13.75 per 100 m^2) were documented. In 2010, 44 (11.0 per 100 m^2) were found. This correlates to higher densities at the WFGB in 2009 (13.75 individuals/100 m^2) and 2010 (11.0 individuals/100 m^2) (Figure 11.3.1).

Table 11.3.1.

Number of Individual Sea Urchins and Lobsters Observed During Surveys in 2009 and 2010

No. of Individuals Observed	Sea Urchins	Lobsters	
	Diadema antillarum	*Panulirus argus*	*Panulirus guttatus*
EFGB 2009	1	0	0
EFGB 2010	2	0	0
WFGB 2009	55	0	0
WFGB 2010	44	0	0

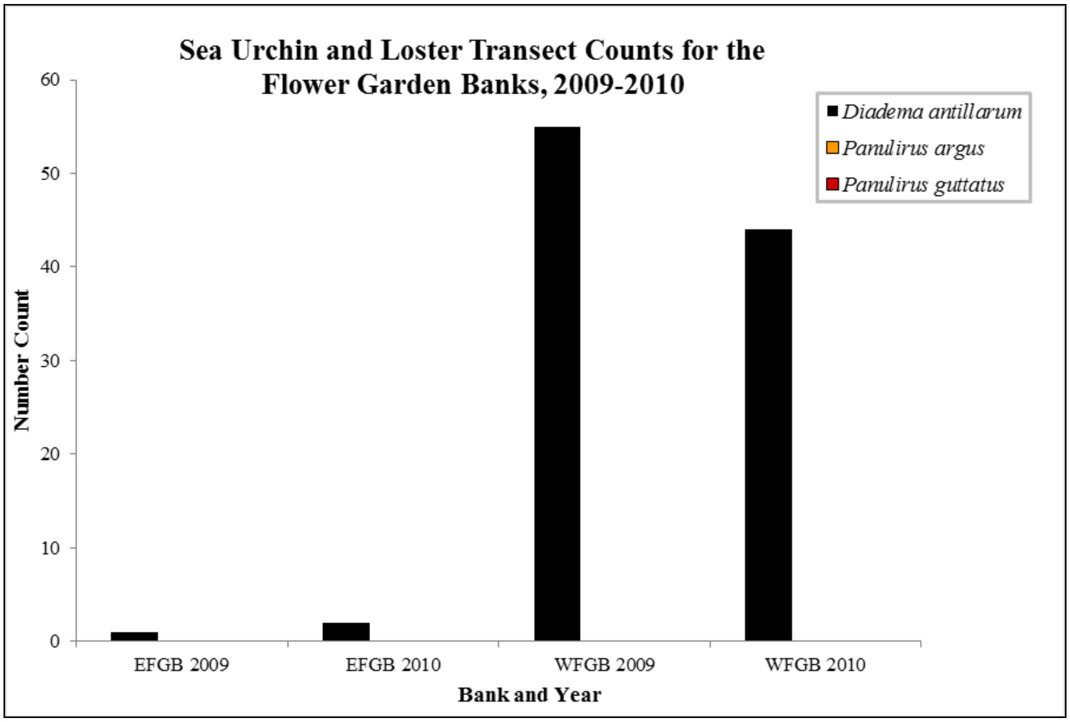
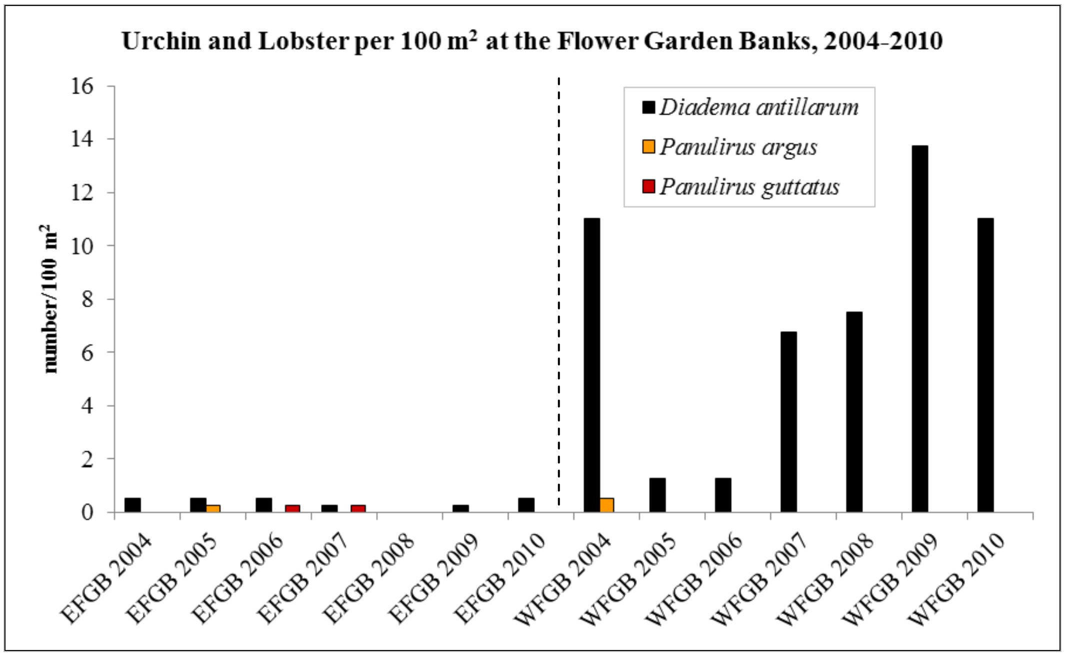


Figure 11.3.1. Sea urchin and lobster counts conducted at the EFGB and WFGB in 2009 and 2010.

11.4. SEA URCHIN AND LOBSTER SURVEYS DISCUSSION

Since 2004, lobster counts on surveys have ranged from zero to two. They are, however, occasionally encountered by divers at other times, so they do occur on the banks in low abundance (Figure 11.4.1).

After the mass die off in 1983, *D. antillarum* populations have not recovered to pre-1983 levels, which were at least 140 individuals/100 m² at the EFGB and 50 individuals/100 m² at the WFGB (Gittings et al. 1998). Post-1984 sea urchin densities dropped to near zero (Gittings and Bright 1987). Sea urchin populations at the EFGB remained low during this monitoring period and were similar to those reported in previous studies (Zimmer et al. 2010). Populations at the WFGB have been consistently higher than the EFGB. Both 2009 and 2010 had abundances among the higest recorded at the WFGB since the die off (Figure 11.4.1). The previous fluctuations in annual density estimates suggest caution in declaring a recovering sea urchin population on the bank; continued monitoring will be required to track and compare temporal changes at both banks.



Data for 2004 to 2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009 and 2010 (Johnston et al. 2012).

Figure 11.4.1. Sea urchin and lobster densities at the FGB from 2004 to 2010.

CHAPTER 12.0: RECOMMENDATIONS

Throughout this report, a number of deficiencies in existing protocols were mentioned, and numerous adjustments would improve the efficiency and quality of data collection efforts. The following are recommendations for improving the monitoring protocols and increasing the scientific value of the monitoring program.

Operational Changes

Below are recommendations that should be considered as immediate improvements to the monitoring program. Most are recommended because they have been identified as deficiencies of the current protocols.

- Install HOBO data loggers at multiple depths.

- Install mid-transect eye bolts along the study site perimeter to improve perimeter video repeatability so that lines will not shift with the current.

- Upload data and service/exchange the Sea-Bird water quality monitoring equipment more frequently (5–8 times per year) to obtain more consistent and accurate results for water quality parameters.

- Improve lateral station methodology and mapping to remove comparison inconsistencies from year to year. Establish new stations and extend cruise days to allow time for this task.

- Add scale bar to T-frame to more accurately measure year-to-year change in colony size.

- Standardize camera, lens, and pole length on T-frame so that photos are always take from the same height above the reef at every station.

- Monitor previously-identified exotic/invasive species on the reefs of the FGB, including *Tubastraea coccinea*, and *Thecacera pacifica*. Monitor for newly arriving exotic/invasive species, such as *Pterois volitans*/*miles*. This will help support management decisions regarding removal programs for exotic or invasive species.

- Obtain additional measurements of the coral heads sampled for sclerochronology, such as width and height, as well as depth of samples.

- Use multiple fish survey techniques, including belt transect, roving methods, and stationary surveys to obtain more comprehensive data, particularly improving data on richness, cryptic species, and fish biomass.

- Improve methods to detect new species records and range extensions to the banks (e.g., *Acropora palmata*). Obtain estimate of tissue loss or growth of *Acropora palmata* for basic condition analyses.

- Future monitoring efforts should include a review of fish biomass and trophic structure at the FGB from 1999 (or earlier if data available) to the present. This will prove to be a useful resource status evaluation tool and help support management decisions.

- Increase the number of lobster and sea urchin surveys instead of the same single transect every year (perhaps conduct them concurrently while doing random transects photos) and note all lobster and urchin species observed during all diving operations.

Experimental Evaluations

The following recommendations may not be critical immediate needs, but represent areas that should be investigated as potential improvements to the monitoring program.

- Install deep stations at the WFGB to compare to deep station coral cover on the EFGB.

- Add survey for coral size class distribution and for coral recruits.

- Additional species other than barracuda and creole wrasse may exhibit differences in abundance throughout the day, resulting in disparate data on morning dives compared to afternoon dives. Diver surveys should be evenly distributed through out daylight hours over a period of two days. More importantly, sampling should be done at the same times throughout the sampling effort. This will allow for the inclusion of changing fish behavior and to test differences between the different sampling times.

- During sea urchin surveys, note the color of the sea urchin spines (e.g., black or white) as part of data collection protocol in order to evaluate anecdotal reports of greater survival among the white-spined morphotype.

Additional Recommendations

- Continue and increase the number of presentations and peer-reviewed publications resulting from this work.

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The Department of the Interior Mission

As the Nation’s principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island communities.

The Bureau of Ocean Energy Management Mission

The Bureau of Ocean Energy Management (BOEM) works to manage the exploration and development of the nation's offshore resources in a way that appropriately balances economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.